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AUTOMATED LONGWALL GUIDANCE AND CONTROL SYSTEMS PHASE II, PART II - RCS, FAS, AND MCS

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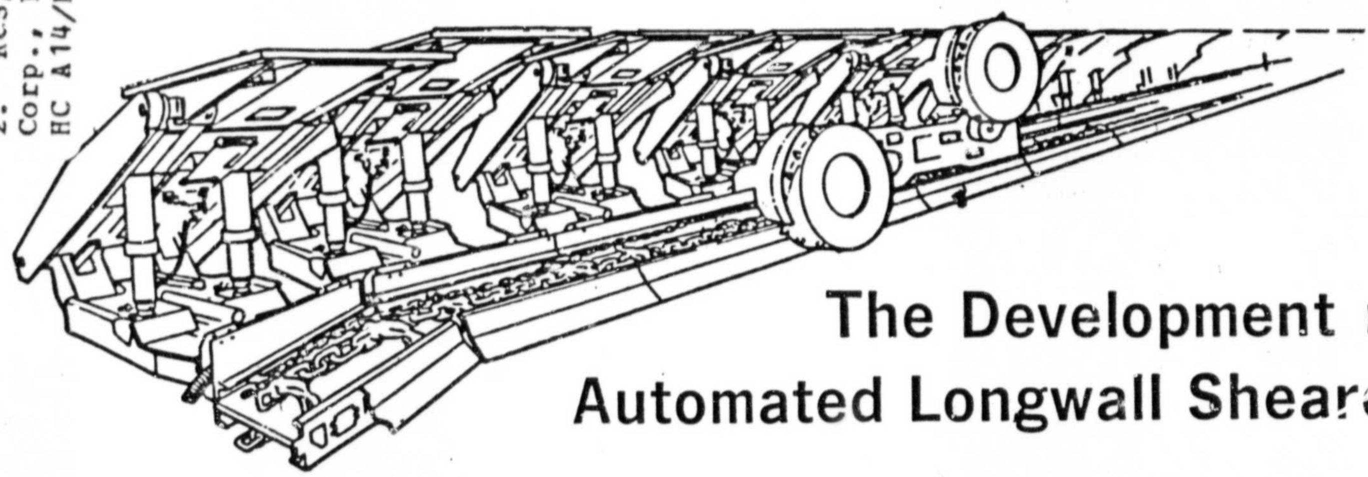

The Development of Automated Longwall Shearer

George C. Marshall Space Flight Center
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Prepared for
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THE
BENDIX
CORPORATION

ENERGY, ENVIRONMENT
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FINAL REPORT

AUTOMATED LONGWALL
GUIDANCE AND CONTROL
SYSTEMS

PHASE II, PART II-RCS
FAS, AND MCS

CONTRACT NO. NAS8-32921

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FOREWORD

This report is submitted in accordance with the requirements of Contract No. NAS8-32921, Data Requirements (DR), MA04A, Phase II, Part II-RCS, FAS and MCS.

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1.0 INTRODUCTION

Dwindling domestic and world oil and gas supplies with the inevitable rise in the price of these fuels have generated deep concern within government, industry, and the general public as to how the energy needs of the country can reasonably and economically be met in the future. The increased use of coal, our most abundant fossil fuel reserve, during the next quarter century will necessitate increasing the efficiency of underground coal extraction. Longwall mining techniques have the potential of greatly increasing the coal yield per acre and coal production per man per shift since it is essentially a continuous mining process. In addition, since longwall is a continuous mining process employing continuous haulage, it is extremely well suited for automation which is the subject of the present study. Automating longwall coal extraction will not only increase production but also minimize the amount of foreign material taken along with the coal thus reducing sorting time and cutter bit wear. In addition, automating or remoting the longwall mining process will increase operator health and safety by removing the miner from the shearer and thus the hazards encountered in the immediate cutting area.

The present study has been divided into two phases. Phase I was primarily concerned with the analyses and simulation of candidate Vertical Control Systems (VCS) and Face Advancement Systems (FAS) (consisting of a Yaw Alignment System and Roll Control System) required to satisfactorily automate the longwall system. The purpose of these studies were to specify the desired overall longwall system configuration for preliminary design which was performed during Phase II of the study. A report outlining the analyses and simulations performed during Phase I of the study which led to a specification of the overall longwall system was issued in September 1978. A report outlining the prototype preliminary design of the Vertical Control System (VCS) portion of the "Automated Longwall Guidance and Control System" was issued in April 1979. This report outlines the proto-

type preliminary design of the Face Advancement System (FAS) consisting of the Yaw Alignment System (YAS) and the Roll Control System (RCS), and the Master Control Station (MCS).

2. SUMMARY

The Automated Longwall Guidance and Control System consists of a Vertical Control System (VCS) for controlling the elevation of the two cutting drums of a double ended ranging arm longwall shearer; a Yaw Alignment System (YAS) for maintaining the longwall face straight and perpendicular to both the headgate and tailgate; a Roll Control System for maintaining proper shearer attitude about its longitudinal axis; and a Master Control Station (MCS) from which the shearer can be operated automatically, or if desired, remotely. The paragraphs that follow will summarize the prototype preliminary design of the Yaw Alignment System (YAS), the Roll Control System (RCS), and the Master Control Station.

2.1 Overall Automated Longwall System Operational Modes - The Automated Longwall System will have the following operational modes:

1) Automatic Mode
2) Manual Mode
3) Remote Mode

These modes of operation are described in the paragraphs that follow:

2.1.1 Automatic Mode - In the automatic mode the following operations will be implemented to occur automatically:

a) The longwall shearer will traverse the longwall face and cut coal automatically via closed loop control of both the roof and floor cutting drums. The shearer shall be capable of traversing the longwall face at velocities of up to fifty feet per minute.

b) The attitude of the shearer about its longitudinal axis will be automatically controlled to within $\pm$ 0.5 deg by an appropriate closed loop controller as the shearer traverses the longwall face.

c) The roof supports will be automatically advanced as longwall mining proceeds. The roof support rams will advance the pan line in accordance to face alignment measurements made as the shearer

traverses the longwall face by a sensor integrated with the shearer so as to affect proper sumping and to maintain face alignment within ± 1 ft across the total longwall face.

d) Shearer turn around will not occur automatically but will be accomplished by a combination of manual and remote modes of operation.

2.1.2 Remote Mode - The remote operational mode for the automated longwall system will primarily be used for system checkout and troubleshooting. There will not be a remote full-up operational mode that will be used to operate the longwall system while mining coal. The reason for this is twofold:

a) It is highly improbable that an operator at the master control station could digest the sensor information required for control of (i.e. Last Cut Follower, Sensitized Pick, CID, Present Cut Follower, etc) the shearer cutting drums and react properly so as to affect satisfactory control. This consideration does not include monitoring the roll sensors and maintaining proper shearer attitude about its longitudinal axis.

b) Since all of the sensor information will be obtained from the processor so as to allow single line digital communication between the shearer and the remote control station, it is quite difficult to postulate a mode of failure that a remote mode could accommodate. In order to control the shearer remotely all of the sensors would have to be operable, the electrohydraulic solenoid control valves would have to be operable, the communication system with the processor would have to be operable, the I/O into the processor would have to be operable, and at least a portion of the processor would have to be operable in order to properly process CID and sensitized pick data. This does not leave very much that could reasonably fail and yet allow the required portions of the system to be operable in order to enable the remote operation to the shearer.

The remote mode in conjunction with the manual mode of system operation will be used for shearer turn around.

2.1.3 Manual Mode - The manual mode of operation will provide for the shearer to be operated by personnel located in the vicinity of and moving along with the shearer as is presently done. The Automated Longwall System hardware will be designed to in noway interfere with the present manual mode of shearer operation.

The manual mode of operation will provide for the manual advance of the roof supports as is presently done. The automated Longwall System hardware will be designed to in noway interfere with present manual roof support advance procedures.

The manual mode of operation in conjunction with the remote mode of operation will be used during shearer turnaround.

2.1.4 System Calibration - This mode of operation will allow the calibration of those system elements that require initial and periodic calibration. These elements include the coal interface detectors, the sensitized picks, and non-contacting last and present cut follower mechanisms should they be present. The manual and remote operational modes in conjunction with auxilliary equipment will be used to perform the required calibrations. As an example, when calibrating coal interface detectors, auxilliary drilling equipment may be used to facilitate and enhance the accuracy of the calibration.

2.2 Yaw Alignment System Performance - The computer simulation results obtained during the Phase I portion of the study indicated a sensitivity to roof support pull back error. The results showed that only 0.1 ft. (1.2 inc) one sigma of roof support pull back error could be tolerated for stable yaw alignment system performance defined to mean indefinate roof support advance without requiring manual intervention for face straightening. This value of roof support pull back error was judged as being too restrictive and higher fidelity and more detailed mathematical and computer simula-

tion models were generated to examine more precisely the allowable Yaw Alignment System errors. Various system configurations were studied which included

a) Actively commanding every roof support
b) Actively commanding every second roof support
c) Actively commanding every third roof support

When every roof support is commanded the hydraulic rams attached to the conveyor are instructed to implement a computed straightening command based on angle cart measurements. When every second or third roof support is actively commanded, the hydraulic rams attached to the conveyor for those supports that are not commanded are unlocked The rams for these supports are then allowed to float to whatever position they reach when those rams that are commanded execute their commands. For each of the system configurations described above three types of control algorithums were examined:

1) Full straightening
2) Periodic Straightening
3) Partial Straightening

Full straightening means that everytime the conveyor is advanced the control will be such as to place it in a straight line perpendicular to both headgate and tailgate. Periodic straightening is accomplished by advancing the conveyor without straightening for several advances and then straightening it. This can be done in several ways. One way is to straighten it regularly; e.g. on the fifth advance. Another way is to straighten it when it gets crooked by more than a specified amount. Partial straightening advances the conveyor so that it is straight - but not fully straight.

The results of the analyses and simulation studies conducted indicate that the one signal ram placement error could not exceed 0.004 ft. (0.048 in) for stable yaw alignment system performance. This is an extremely small error and great difficulty would be en-

countered in designing a conveyor placement system of such accuracy. When placing every second or third conveyor section ram placement error of 0.1 ft one sigma have little effect on system performance. In addition the roof support pullback error that could be tolerated is as much as 0.20 ft (2.4 in) one sigma which can be met by present longwall conveyor and roof support systems. In general, the results indicated that placing every second or third roof support yielded similar allowable system errors (i.e. measurement, placement, and pull up errors) for stable yaw alignment systems performance.

The investigation into the various control algorithms listed above indicated that full straightening yielded the poorest system efficiency defined as follows

$$\text{Efficiency} = \frac{\text{Actual Volume of Coal Cut}}{\text{Volume of Coal Cut with Full advance and No Errors}}$$

The system efficiency for full straightening on every pass was approximately 76 percent for a one sigma roof support pull up error of 0.2ft. system efficiency for partial straightening, on every pass for a one sigma roof support pull-up error of 0.2 ft was 85 percent, while for periodic straightening an efficiency of 85.5 percent was achieved for the same conditions.

It can be seen that combining the periodic and partial straightening control algorithms i.e. for only partially straighten the conveyor periodically when it gets sufficiently out of alignment, increased yaw alignment system efficiency could be achieved. A simulation combining these two control algorithms was performed and system efficiency increased to approximately 88 percent for a maximum one sigma roof support pull up error of 0.2 ft..

Therefore, the recommended yaw alignment system configuration and control algorithm is to actively place every third roof support with periodic partial straightening. All of the results described above are discussed in detail in Section 3.0.

2.3 Yaw Alignment System Electronic Design The Yaw Alignment System consists of the angle cart, electronics in the Electronic Control Module (ECM) and electronics mounted on each of the roof supports along the face. The angle cart measurements, made as the shearer traverses the face are sent to the ECM. On the basis of these measurements the face(i.e. conveyor) alignment is computed and control signals generated for the actively controlled roof supports. These roof support advance commands are sent from the ECM via the communication link to the MCS and then to the individual roof supports utilizing a time synchronous multiplexing technique. Once the commands are received by the roof supports they are stored and implemented at the properly prescribed time. The electronics control box on the individual roof supports control the roof support advance, monitor the sequencing and send a signal back to the main processor in the ECM once the roof support advance commands have been properly completed. The electronic packages on all of the roof supports are active, including those supports whose placement rams are not actively commanded, since each of the roof supports must advance and hence its sequencing must be monitored and controlled.

The roof support commands required for proper sumping are contained in firmware (PROM) and are superimposed on the roof support advance/straightening commands. Only one type of sumping technique can be accomodated by a particular set of electronic hardware. Should a different sumping procedure be desired, the chip containing the sumping commands would have to be reprogrammed or replaced with the desired sumping commands.

Since the placement of rams of every third roof support is commanded there are three sets of commands that can be generated i.e. commanding roof supports 1,4,7, etc., 2,5,8,etc. and 3,6,9 etc. the YAS has the capability of commanding any of these sets depending on the conditions of the YAS electronics. For instance should the ram placement command loop on roof support seven fail then the commands could be shifted to the

2,5,8 or 3,6,9 sequences thus increasing overall system reliability. This change over is easily accomplished by setting a switch on the Master Control Station (MCS) to the roof support command sequence desired.

The power for the roof support mounted electronics is furnished by the MCS power supply mounted on the stageloader. In order to obtain a reasonable number of lines which are intrinsically safe to furnish the required power to the roof support mounted electronics it is assumed that at most three supports could be advanced simultaneously. A maximum of three was chosen since this conforms with the hydraulic limit of present roof support systems. In addition it is assumed that each of the solenoid operated valves on a roof support needed for its advance will be operated serially yielding a maximum of three solenoid valves operating at any one time. With the above stated restrictions a reasonable number of power lines redundently current limited to intrinsically safe levels are needed to furnish the required power to the roof support mounted electronics. For a more detailed discussion of the Yaw Alignment electronics and power distribution see Sections 4.0 and 8.0 respectively.

2.4 Roll Control System Performance Studies - Analytical and computer simulation studies performed during the Phase I portion of the study indicated that roll control system performance was extremely sensitive to cross axis acceleration. A cross axis acceleration of 2.8 x 10.3g RMS within the control loop bandwidth of 0.05 Hz resulted in an RMS roll attitude error of 0.712 degrees. This sensitivity was judged too high and higher fidelity and more detailed mathematical and computer models were developed to more precisely examine the cross axis acceleration that could be tollerated while still maintaining satisfactory roll control. A number of alternate roll control system implementations were considered in addition to the base line concept of a shearer mounted inclinometer controlling in real time as the shearer traverses the longwall face. These alternate roll control systems implementations are listed below:

a) Inclinometers mounted on a seperate cart

b) Inclinometers mounted on the conveyor proper

c) Inclinometers mounted on the roof supports

d) Inclinometers, mounted on the shearer and controlling during a clean up pass

e) Inclinometers mounted on shearer and measure without cutting on clean up pass

f) Inclinometers mounted on shearer, stop at various points and measure roll.

For a more detailed explanation of each of the alternate roll control concepts listed above see Section 5.2.2 through 5.2.7

The results of the simulation studies indicated that for a shearer mounted inclinometer 4.5 x 10.3g RMS of cross axis acceleration in the roll control loop bandwidth of 0.05 Hz resulted in an RMS roll attitude error of 0.3 degrees. This represents an improvement of approximately a factor of four over those results originally obtained in the Phase I portion of the study. It is presently felt that with the increased tolerance to cross-axis accelleration indicated by the more detailed analyses and simulation conducted, the baseline roll control system implementations will perform satisfactorily, in the mine environment. It is also clear that the shearer mounted inclinometer controlling roll as the shearer traverses the longwall face mining coal is the simplest of the implementations considered and does not interfere with mining operations. Hence, the baseline roll control system configurations is the recommended system implementation.

For a discussion of the results obtained for the alternate roll control system implementation listed above see Section 5.4.2.

2.5 <u>Roll Control System Electronic Design</u> - The electronics needed to affect roll control is located in the ECM. The output of the inclinometer is fed to the ECM where the central computer processes the data and issues the approximate roll actuator commands to accomplish roll control. For a more detailed discussion of the roll control loop electronic implementation see Section 6.0.

2.6 Master Control Station Electronic Design - The Master Control Station (MCS) located and mounted on the stageloader is the primary man/machine interface and the central monitoring and command station of the Automated Longwall System. Dedicated displays are furnished by which the console operator can monitor longwall system performance during the alternating modes of operation. Various malfunction indicators are present that alert the console operator to off minimal and potentially dangerous conditions. In addition the status of various other elements in the longwall mining system other than the automation equipment are also monitered. These include currents in the panel conveyor, two stage loader, and two face conveyor motors the status of which are critical if coal spillage is to be avoided if one of these motors/conveyors are overloaded or fail.

Appropriate controls and displays are furnished on the MCS to enable an operator to operate the Automated Longwall System remotely. However as outlined in Section 2.2 the remote mode of operation will be used primarily for system checkout, calibration, and troubleshooting and hence the controls and displays are not designed to enable the convenient mining of coal.

The MCS has a digital address system (DAS) through which virtually any sensed, computed, and control variable can be called up and displayed on its alphanumeric display. The DAS will be used extensively during system checkout, and malfunction/fault isolation to enable a fast and economical means of performing these functions. The DAS is also used to override numerous system holds that are included in the design to protect the longwall from inadvertant damage. However there are system holds that cannot be overrided by DAS command specifically those that would result in hazardous situations. In addition provision is made for the connection of a portable recorder or printer to the MCS and upon the proper DAS command the programs contained in the ECM and MCS microprocessos will be printed out in order to facilitate system debugging. It should be noted that a special

key is required to be inserted in the MCS panel to enable remote system operation or to activate the DAS. This is done as a safety precaution to prevent inexperienced console operators from operating the system remotely or commanding the system through the DAS.

Another prime function of the MCS is to provide the central microprocessor in the ECM with required parametric data needed for satisfactory control system operation. Since non-volitile memory is expensive, and using battery power on the face to float the memory when power goes down is undesirable from permissibility considerations, a means must be found to enable imputting parametric data needed for control that changes periodically as a function of mining conditions. These parameters include coal seam thickness, desired headcoal and bottom coal, maximum deviation between two successive cuts, seam indination, sensitized pick discrimination level, and coal interface detector calibration data. All of the above parameters change periodically with mining condition and hence cannot be put into the permanent microprocessor memory. In order to overcome this problem thumbwheel switches are provided for all those functions on the MCS which are set to the appropriate values for the parameters they represent. The microprocessor routinely reads those switches. Power interruption will not cause any problem since once power is restored the needed parameters will be read by the microprocessor on the next sampling cycle.

The parametric data required for CID calibration deserves specific mention. In order to interpret what coal thickness corresponds to a measured number of counts some sort of CID calibration data relating count to coal thickness is required by the microprocessor. This sort of data can be furnished in terms of a look-up table where the number of counts obtained for particular thicknesses of coal is recorded. A look-up table format for defining CID calibration would require a considerable amount of data to be made available to the microprocessor precluding the use of thumbwheel switches on the MCS. Therefore if

a table look up format would be employed the data in the table would have to be permanently programmed into the microprocessor memory to avoid loss during power shutdown if non-volitile memory or battery power is to be employed. Programming such a look-up table in the microprocessor memory implies that the hardware whould have to be changed or reprogrammed via a PROM anytime a CID recalibration would be required.

The method by which CID calibration and data is presented to the microprocessor in order to avoid the problems associated with a look up table is to use a polynomial curve fit. Examination of the curve relating count rate to coal thickness indicates that a second and certainly a fourth order polynomial is sufficient to characterize it. Assuming that a forth order polynomial would be employed only five coefficients would vary as a function of CID calibration and would have to be presented to the microprocessor. This can easily be furnished by thumbwheel switches on the MCS which is the way it is configured.

In addition the MCS microprocessor will have the capability of computing the coefficients required for the polynomical fit. This will be accomplished by inserting measured counts vs. known coal depth via the DAS and the MCS microprocessor would have the capability of computing the required coefficients. These coefficients will then be read on the DAS alphanumeric display and the thumbwheel switches on the MCS set appropriately.

SECTION 3

YAW ALIGNMENT SYSTEM

3.1 FUNCTIONAL DESCRIPTION

In long wall mining after coal is cut along the face, the conveyer is pushed forward in preparation for the next cut by the roof support system. A typical sequence of operations is shown in Figures 3-1 through 3-4. In Figure 3-1 the conveyer is straight, the roof support shields have been pulled up and the shearer is at the headgate. The tailgate end of the conveyer is then advanced in preparation for the next cut as shown in Figure 3-2. Figure 3-3 shows the shearer at the tailgate end of the conveyer after it has cut the coal face. Finally, in Figure 3-4 the headgate end of the conveyer is pushed forward and the roof supports have been advanced along the tailgate end of the conveyer. The shearer can now travel from the tailgate to the headgate making a cleanup cut at the tailgate end of the conveyer and completing the cut at the headgate end. After the cut, the remaining roof supports are advanced. In this position the conveyer, shearer and roof supports are back in their original positions ready for another cycle of operation.

In the manual mode of operation, the miners push the conveyer a full stroke and then after cutting, advance the roof supports. Care must be taken to straighten the conveyer after the roof supports advance. This is accomplished by the miners sighting down the conveyer and alternately adjusting the conveyer and roof supports so they are straight. If care is not taken, the conveyer will rapidly get out of alignment resulting in the roof supports being unable to advance properly.

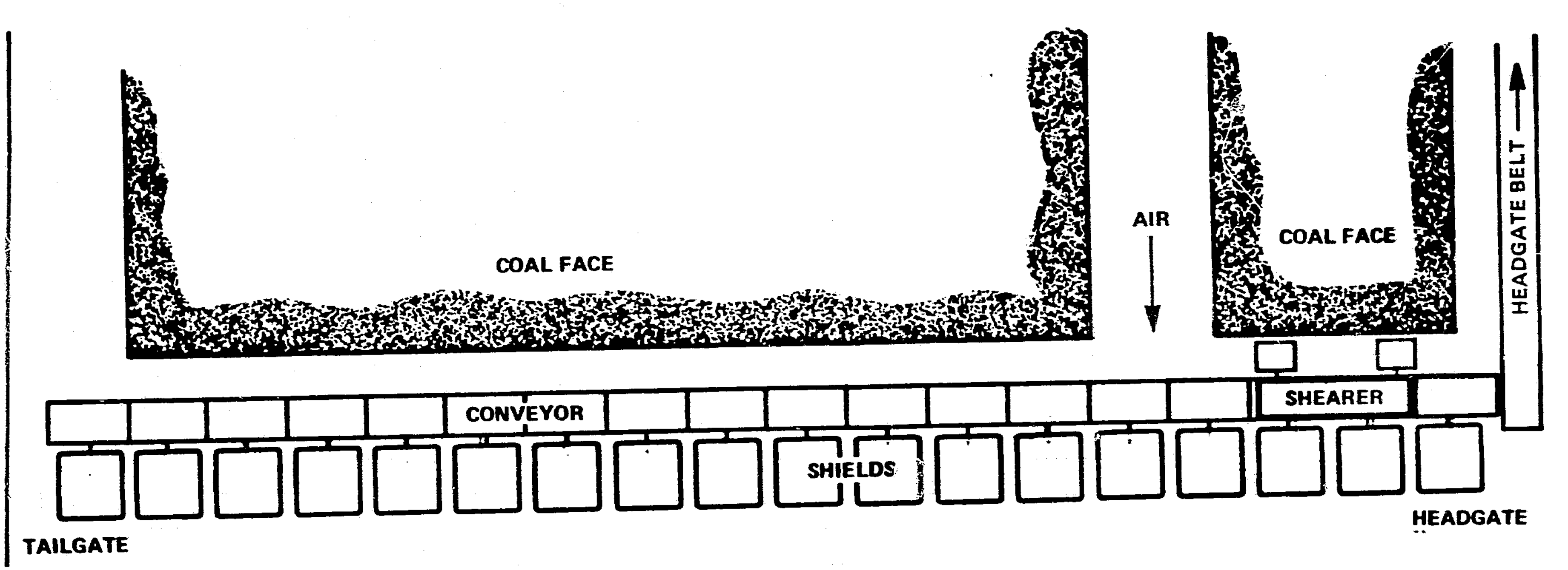


Figure 3-1. Conveyor Advance - Sequence of Operations 1

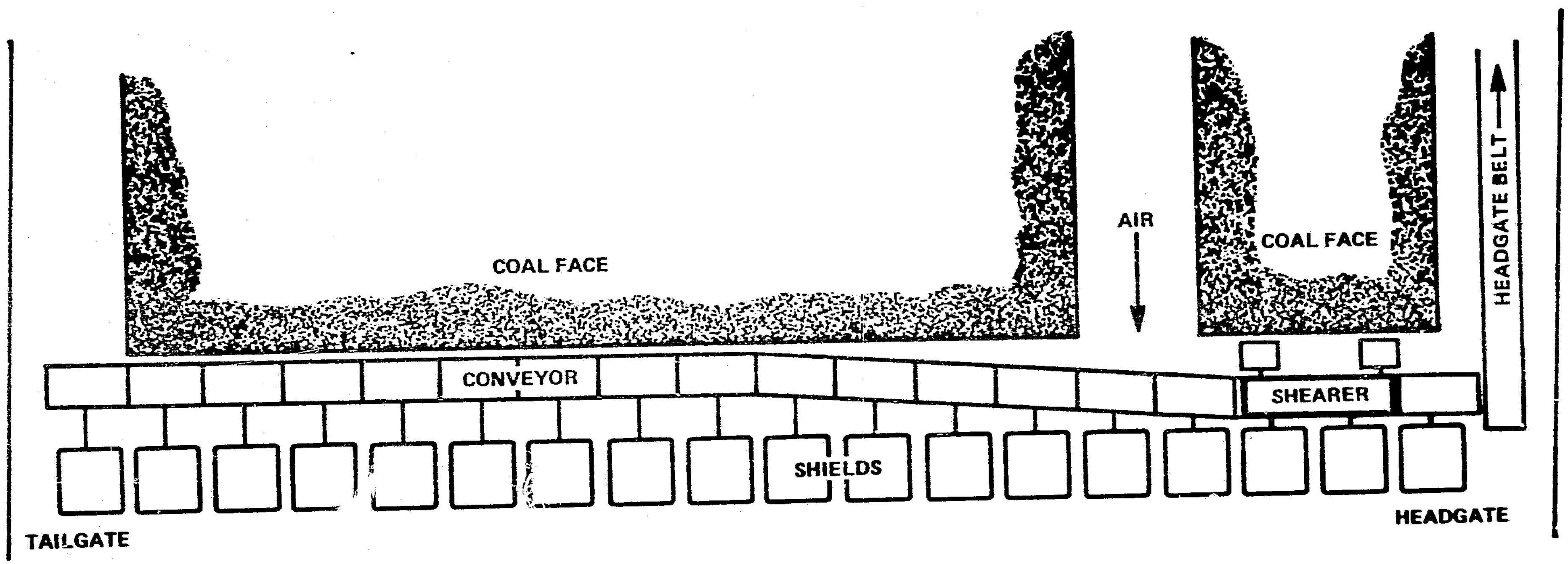


Figure 3-2. Conveyor Advance Sequence of Operations 2

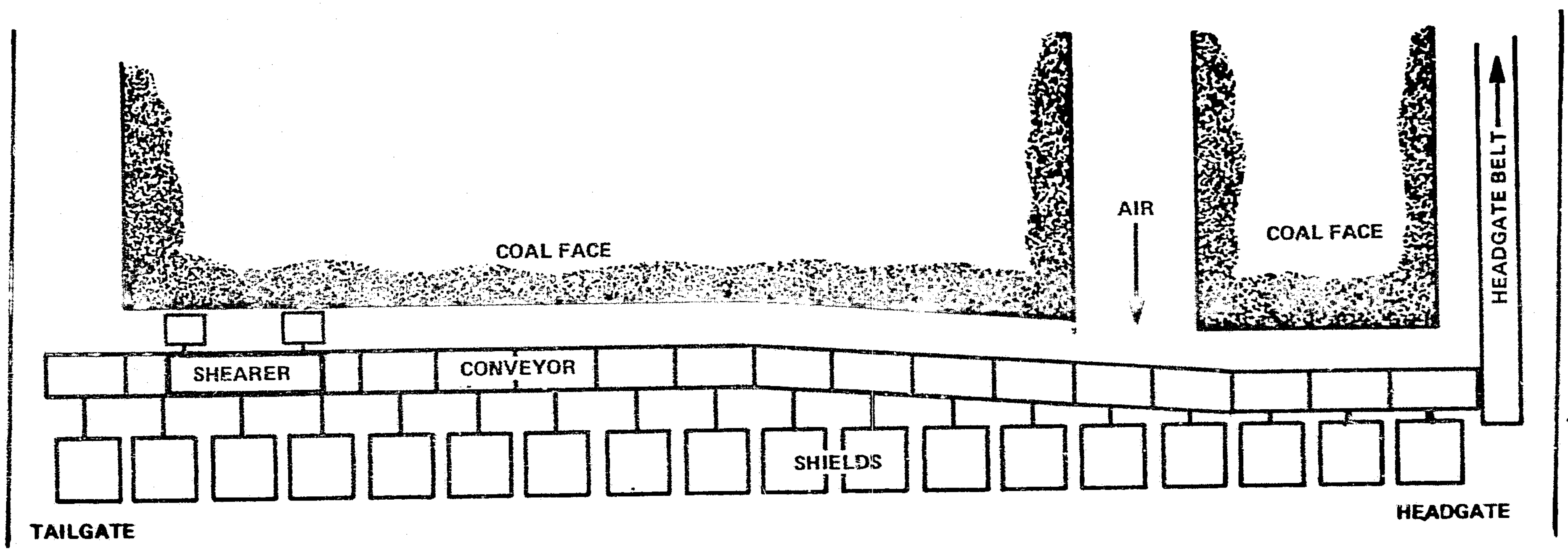


Figure 3-3. Conveyor Advance - Sequence of Operations 3

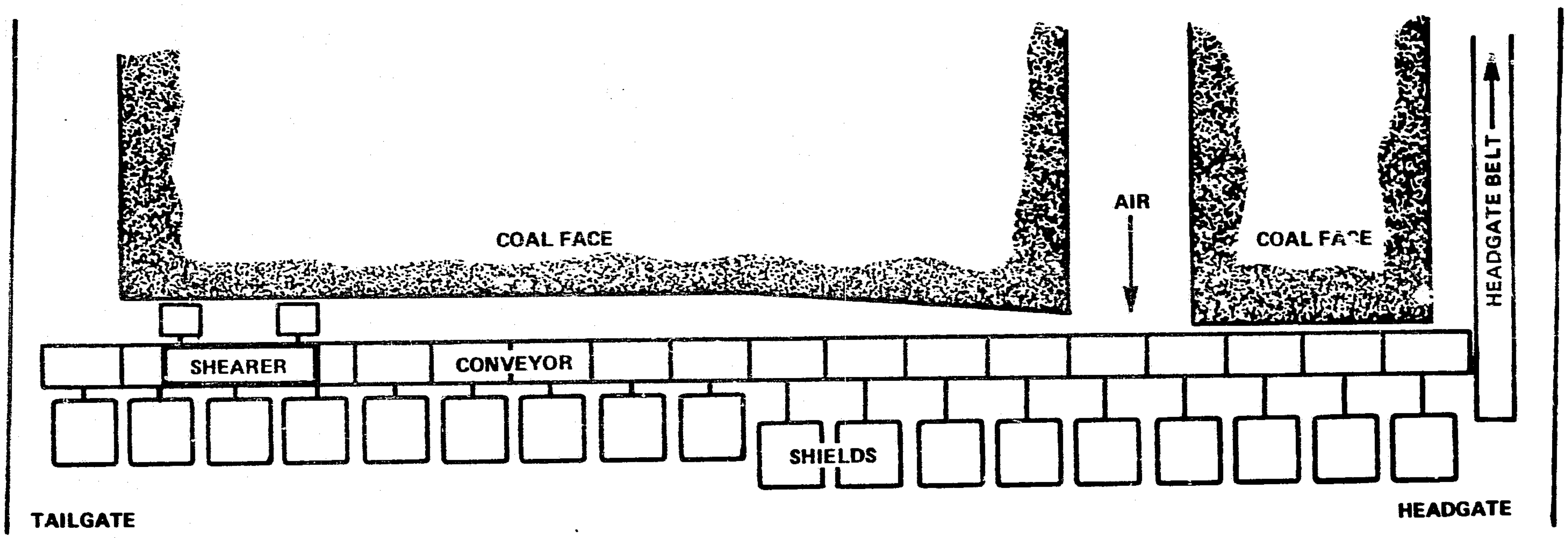


Figure 3-4. Conveyor Advance - Sequence of Operations 4

In an automatic system, measurements are made to determine the conveyer yaw alignment. Any misalignment is corrected by pushing the conveyer different amounts along the face.

The measurements can be taken when the system is in the sequence of operations as shown in Figure 3-4. The conveyer is relatively straight at this time and measurements can be made as the shearer travels from the tailgate to the headgate.

In the Phase I study two types of measurement devices were proposed. One was an angle cart measurement system that measured the relative angle between two conveyor sections. The other was a directional gyro system that measured the angular orientation of a conveyor section with respect to a directional reference. Studies in Phase I led to recommending the use of the angle cart type of measuring device. It was also recommended that a more dynamically correct simulation be developed to study the effect of pullup errors.

As a result, in this present study only the basic angle cart type of measuring system is considered. Also, a geometrically correct simulation of the conveyor has also been developed. This simulation allows studies of the effect of placing (pushing) every conveyor section every second conveyor section, or every third conveyor section. It also allows studies of periodically (not on every advance) straightening the conveyor and partially straightening the conveyor.

Detailed descriptions of the yaw control system which consists of the basic angle cart measurement system, and the control (or straightening) algorithms are presented in the following sections.

3.2 YAW CONTROL SYSTEM

The yaw control system consists of the measuring system, the computation of the yaw profile, the determination of the placement commands, and finally the placement or advancement of the conveyor. The basic angle cart measurement system uses the location of the conveyor end points and the angles between adjacent conveyor sections to compute the yaw profile. The conveyor is then advanced by a control law that not only straightens the conveyor, but also maximizes the amount of coal cut.

3.2.1 Basic Angle Cart Measurement System

The angle cart measures the angle θ between two conveyer sections. Knowing all the θ angles, the location of the conveyer end points, and the length L of each conveyer section allows one to determine the YAW profile of the conveyer. From the geometry shown in Figure 3-5 the angle cart measures the angles θ_2 through θ_N (assuming N con veyer sections). The location of Y_0 and Y_N can be measured with respect to surveyor stakes. The computed Y coordinates $\hat{Y}_i$ of the end points of each conveyer section are found as follows

$$\hat{Y}_1 = L \sin \hat{\theta}_1 + Y_0$$

$$\hat{Y}_2 = \hat{Y}_1 + L \sin (\hat{\theta}_1 + \hat{\theta}_2)$$

$$\vdots$$

$$\hat{Y}_n = \hat{Y}_{n-1} + L \sin \sum_{i=1}^{n} \hat{\theta}_i$$

$$\vdots$$

$$\hat{Y}_N = \hat{Y}_{N-1} + L \sin \sum_{i=1}^{N} \hat{\theta}_i$$

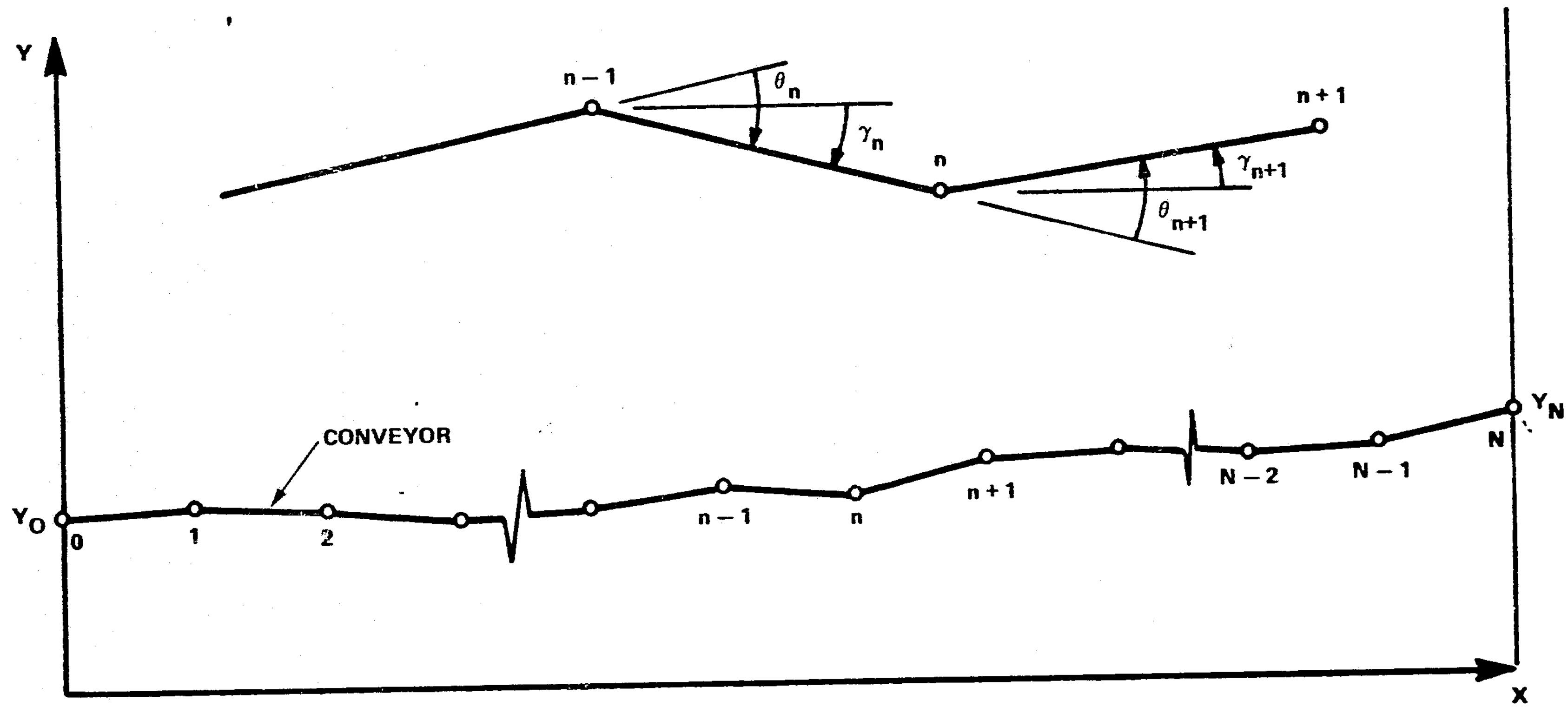


Figure 3-5. Conveyor Geometry

where $\hat{\theta}_i$ are the measured angles. Since all the angles are measured except θ_1, it must be determined in another manner. The last equation above can be written

$$\hat{Y}_N = L \sum_{i=1}^{N} \sum_{j=1}^{i} \hat{\theta}_J + Y_o$$

Note:

$$\gamma_i = \sum_{j=1}^{i} \theta_j$$

where γ_i is the angular orientation of the i^{th} conveyer section with respect to the horizontal. Assuming small angles

$$Y_N = Y_o + L\gamma_1 + L\gamma_2 + \ldots + L\gamma_N = Y_o + L \sum_{i=1}^{N} \gamma_i = L \sum_{i=1}^{N} (\sum_{j=1}^{i} \theta_i) + Y_o$$

Assuming that $\theta_1 = 0$ yields

$$\hat{Y}_N = L \sum_{i=2}^{N} \sum_{j=2}^{i} \hat{\theta}_J + Y_o$$

The value of θ_1 can then be computed by

$$\hat{\theta}_1 = - \frac{\hat{Y}_N - Y_N}{NL}$$

As a result, the yaw profile is determined by

$$\hat{Y}_n = L \sum_{i=1}^{n} \sum_{j=1}^{i} \hat{\theta}_j + Y_o \qquad n = 1,2,3,\ldots,N$$

3.2.2 <u>Yaw Control Algorithms</u>

The yaw control laws considered for straightening the conveyor are

1 Full Straightening
2. Periodic Straightening
3. Partial Straightening

Full straightening means that the conveyer after advancing will be a straight line. In order to advance it the maximum amount the conveyer section farther behind is advanced the maximum amount and all the other sections are then advanced lesser amounts so the conveyer is straight. This is accomplished using the following algorithm:

$$\Delta Y_{pn} = Y_A + \hat{Y}_{min} - 0.5\ (\hat{Y}_n + \hat{Y}_{n-1})$$

where ΔY_{pn} is the distance the n^{th} section should be advanced, Y_A is the maximum advance, $\hat{Y}_{min}$ is the minimum measured Y-coordinate of the conveyer, and $\hat{Y}_n$ and $\hat{Y}_{n-1}$ are the computed end coordinates of the n^{th} conveyer section.

Periodic straightening is accomplished by advancing the conveyer without straightening for several advances and then straightening it. This can be done in several ways. One way is to straighten it regularly; e.g. on the fifth advance. Another way is to straighten it when it gets crooked by more than a specified amount.

Partial straightening advances the conveyer so that it is straight - but not fully straight. This is accomplished by modifying the full straightening commands ΔY_{pn} as follows:

$$\Delta Y_{pn(partial)} = \frac{Y_A - K}{Y_A} \Delta Y_{pn} + K$$

where $\Delta Y_{pn(partial)}$ is the distance the n^{th} section is advanced for partial straightening and K is the partial straightening parameter - having values between 0 and Y_A. Figure 3.6 shows the relationship between ΔY_{pn} and $\Delta Y_{pn(partial)}$ and Figure 3.7 shows a sketch of conveyer showing the effect of partial straightening.

3.3 DESCRIPTION OF THE YAW ADVANCEMENT SYSTEM SIMULATION

As described in Section 3-1, the yaw advancement system consists of pushing the conveyer forward, pulling the roof supports up, measuring the yaw profile and then pushing the conveyer forward again. This same sequence of operations is modeled in the yaw advancement simulation (see Figure 3-8). In the present phase of study the conveyer simulation is geometrically correct so that a more accurate evaluation of system performance can be accomplished.

Conveyer Placement

Each section of the conveyer is pushed forward an amount given by the placement command ΔY_{pn} plus a placement error ϵ_{pn}, i.e.,

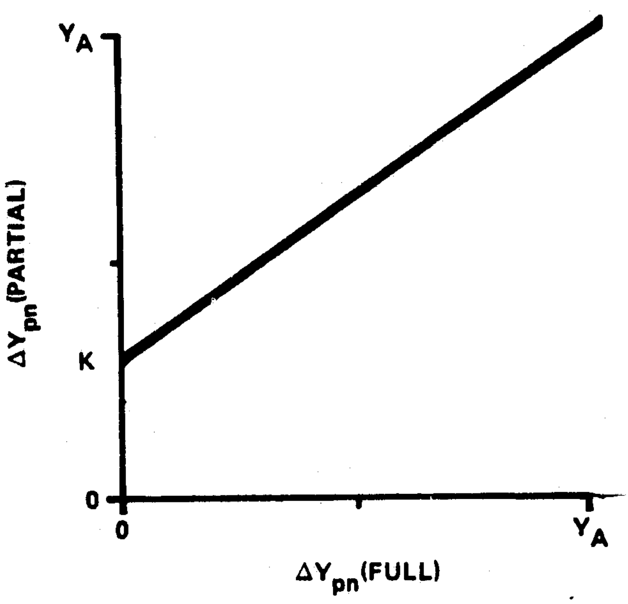


Figure 3-6. Relationship Defining the Difference Between Placement Commands for Full Straightening and Partial Straightening

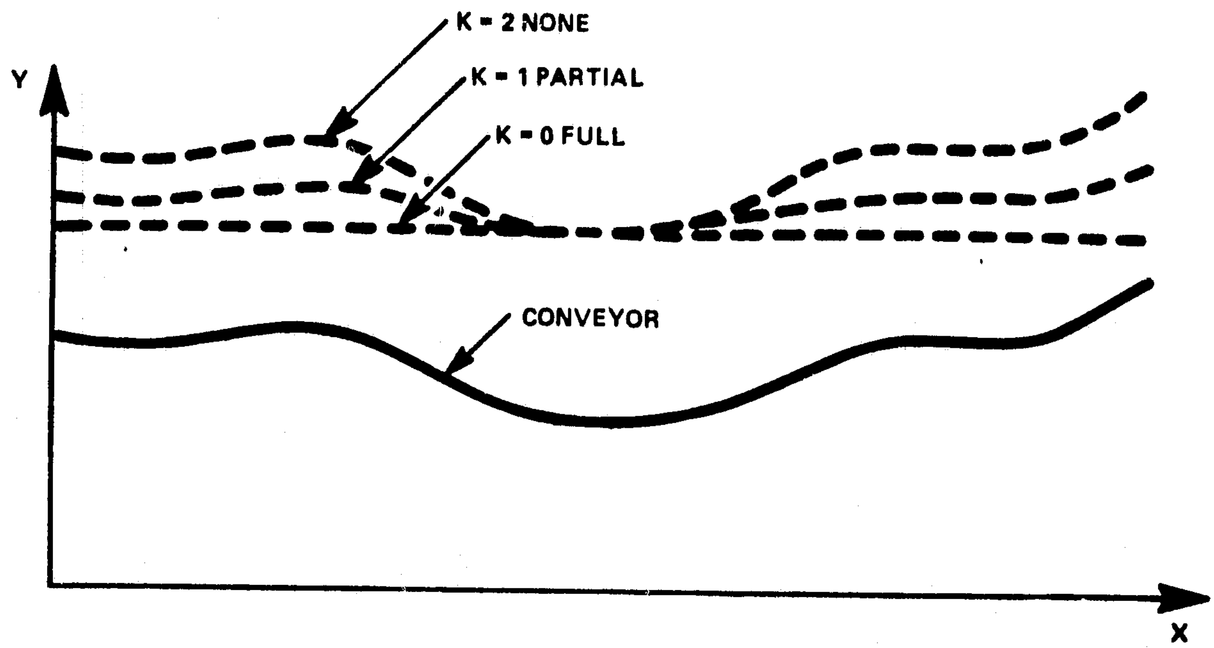


Figure 3-7. Sketches of the Yaw Profile Showing the Effect of Various Values of the Partial Straightening Parameter

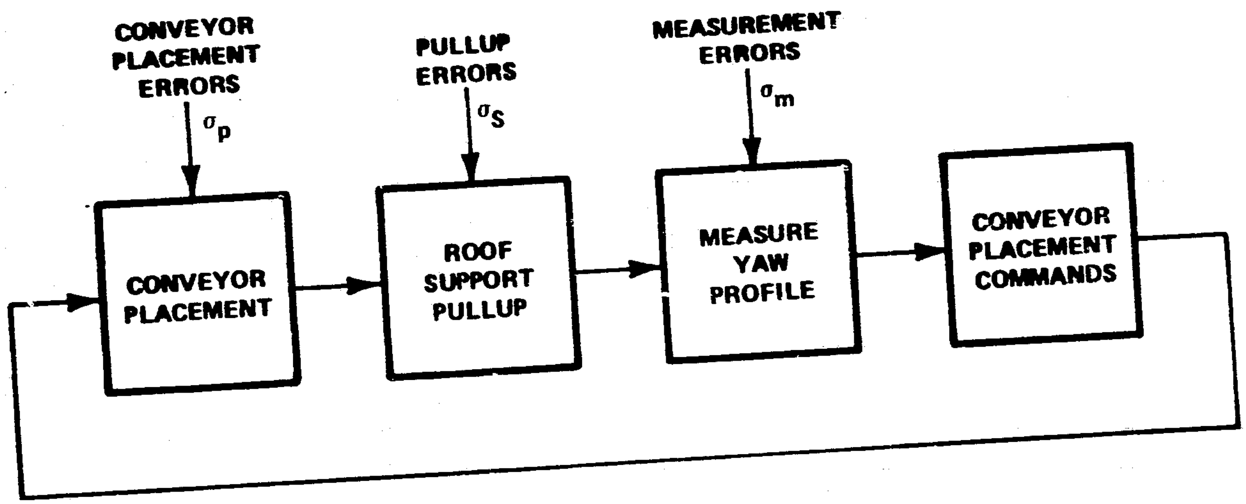


Figure 3-8. Yaw Advancement Simulation

$$\Delta Y_n = \Delta Y_{pn} + \epsilon_{pn}$$

where ϵ_{pn} is sampled from a normal distribution $(0, \sigma_p^2)$. If every section is pushed then n=1,2,...N. If every second section is pushed the n=1,3,5... . If every third section is pushed then n=1,4,7,... . The amount the conveyer is pushed forward ΔY_n is limited between zero and the full ram stroke Y_A. The equations are

$$\text{If } \Delta Y_n > Y_A, \ \Delta Y_n = Y_A$$

$$\text{If } \Delta Y_n < 0, \ \Delta Y_n = 0$$

The conveyer sections are pushed from their midpoints. Defining Y_{mn} as the Y-coordinate of the midpoint of the n^{th} conveyer section, then the Y-coordinate after pushing is given by

$$Y_{mn}^{k} = Y_{mn}^{k-1} + \Delta Y_n$$

where the superscripts define the sequence before and after pushing.

The conveyer geometry is computed by minimizing the values of the angles between conveyer sections. This is accomplished as follows.

Geometric constraint equations are written for m = 1,2,3 where m = 1 indicates that every conveyer section is pushed, m = 2 indicates every second section is pushed and m = 3 indicates every third section is pushed. The constraint equations are

$$\frac{Y_{mi+1} - Y_{m(i-1)+1}}{mL} = \sum_{j=i}^{m(i-1)+1} \theta_j + \frac{1}{2m} \sum_{k=1}^{m} (2m-2k+1)\, \theta_{m(i-1)+k+1}$$

$$i = 1,2, \ldots \left[\frac{N-1}{m}\right]$$

where Y_i is the Y coordinate of the conveyer section end points, θ_i is the angle between two adjacent sections, N is the number of conveyer sections, L is the length of a conveyer section, and the quantity in the brackets is rounded to the next lowest integer.

For N=80 and m=1,2,3, there are 79, 39, 26 constraint equations, respectively.

Let $\theta = (\theta_1, \theta_2, \ldots . \theta_N)^T$

and $b = (b_1, b_2, \ldots . b_\ell)^T$

where

$$b_i = \frac{Y_{mi+1} - Y_{m(i-1)+1}}{mL}$$

and $\ell = \left[\frac{N-1}{m}\right]$

A matrix equation of the constraint equations is

$$A \theta = b$$

Where A is an ℓ x N matrix whose elements are the coefficients of the θ's in the constraint equations.

The conveyer angles are found by

$$\theta = A^T (A A^T)^{-1} b$$

This equation gives a minimum energy solution of the constraint equations. If the absolute value of any of the θ_i angles are greater than θ_{max} (θ_{max} = 4 degrees), then these angles are set to θ_{max} (with the appropriate sign), the constraint equations are revised, and another solution for the θ_i angles is computed. If a solution is not found within five iterations, then it is assumed that no solution exists and that the conveyer will be broken or bent if the attempt is made to place it as desired.

Roof Support Pullup

After the conveyer has been pushed forward, the shearer will move along the conveyer making its cut. This operation, however, does not affect the conveyer yaw profile. The roof supports are then pulled up. This operation affects the conveyer profile by pulling the conveyer back as the roof supports are pulled forward. This operation is simulated by subtracting a pullup error from the Y-coordinate of the midpoint of each conveyer section, i.e.,

$$Y_{mn}^{k} = Y_{mn}^{k-1} - |\epsilon_{sn}|$$

where ϵ_{sn} is the pullup error and is sampled from a normal distribution $(0, \sigma_s^2)$.

A yaw profile, after this pullup error, is computed in the same manner as for the conveyer placement except that in this case it is assumed that m = 3 and no iterations of the solution are allowed.

Measure YAW Profile

For the basic angle cart measurement system the conveyer angles θ_2 through θ_N are measured. Therefore, for all those angles, errors are added, i.e.,

$$\hat{\theta}_i = \theta_i + \epsilon_i + b$$

where ϵ_i is the measurement error and is sampled from a normal distribution $(0, \sigma_m^2)$ and b is a bias error with a normal distribution

$(0, \frac{\sigma_m^2}{N})$.

The yaw profile is then computed as described in Section 3.2.1. The equations are

$$\hat{Y}_N = L \sum_{i=2}^{N} \sum_{j=2}^{i} \hat{\theta}_j + Y_o$$

$$\hat{\theta}_1 = - \frac{\hat{Y}_N - Y_N}{NL}$$

$$\hat{Y}_n = L \sum_{i=1}^{n} \sum_{j=1}^{i} \hat{\theta}_j + Y_o$$

<u>Conveyer Placement Commands</u>

The conveyer placement commands ΔYpn are determined using the computed conveyer Y-coordinates $\hat{Y}_n$. It is desired to advance the conveyer as far as possible and at the same time straighten it when it is out of alignment. The algorithms for computing the placement commands are as follows:

1. Full Straightening

$$\Delta Y_{pn} - Y_A + \hat{Y}_{min} - 0.5\ (\hat{Y}_n + \hat{Y}_{n-1})$$

2. Periodic Straightening

Regular

$$\Delta Y_{pn} = Y_A + \lambda\ [\hat{Y}_{min} - 0.5\ (\hat{Y}_n + \hat{Y}_{n-1})]$$

where

λ = 1 on every k advance

= 0 on all other advances

Irregular

$$\Delta Y_{pn} = Y_A + \lambda\ [\hat{Y}_{min} - 0.5\ (\hat{Y}_n + \hat{Y}_{n-1})]$$

where

$\lambda = 0$ for $\Delta Y \leq \Delta$

$= 1$ for $\Delta Y > \Delta$

and where $\Delta Y = \hat{Y}_{max} - \hat{Y}_{min}$. The parameter Δ specifies how crooked the conveyer can get before it is straightened.

3. Partial Straightening

$$\Delta Y_{pn} = \frac{Y_A - K}{Y_A}\ [Y_A + \hat{Y}_{min} - 0.5\ (\hat{Y}_n + \hat{Y}_{n-1})] + K$$

where K is a parameter defining the amount of partial straightening.

A combination of periodic and partial straightening can be accomplished by using a combination of the above algorithms, i.e.

$$\Delta Y_{pn} = \frac{Y_A - K}{Y_A} \left\{ Y_A + \lambda \left[\hat{Y}_{min} - 0.5 \left(\hat{Y}_n + \hat{Y}_{n-1} \right) \right] \right\} + K$$

3.4 YAW CONTROL SYSTEM PERFORMANCE

The yaw control system performance was determined by exercising the yaw advancement simulation.

The conveyer initial position was a straight line. Then the conveyer was pushed forward (with placement errors, σ_p) and the roof supports were pulled up (with pullup errors, σ_s). Measurements were then made (with measurement errors, σ_m) and the yaw profile computed. Next, conveyer placement commands were computed in preparation for the next advancement.

In order to determine tolerable measurement errors, a placement error σ_p and a pullup error σ_s were selected and then twenty advances were made with $\sigma_m = 0$. The measurement error was then increased in small steps each time advancing the conveyer twenty times. As the measurement error was increased, the conveyer became more and more crooked so that for some value of σ_m the conveyer cannot advance twenty times without commanding a negative placement of the conveyer or having no solution to the conveyer geometry. Such commands would require the conveyor to be pulled back which is impossible or they would break the conveyor. As a result, the next lower value of σ_m was deemed the maximum tolerable measurement error.

Studies were made to determine the effect of placing every conveyer section, every second conveyer section, and every third conveyer section. System performance was also evaluated for controlling yaw by full straightening, periodic straightening, and partial straightening. The evaluation criteria was system error tolerance and efficiency. Efficiency is defined by

$$\text{Efficiency} = \frac{\text{Actual Volume of Coal Cut}}{\text{Volume of Coal Cut with Full Advance and No Errors}}$$

3.4.1 Effect of Placing Every, Every Second, and Every Third Conveyer Section

As described in Section 3.3, the yaw advancement simulation was designed to command (place) every individual conveyer section, or every second conveyer section or every third conveyer section. The effect of placement errors, roof support pullup errors, and angle cart measurement errors on the yaw control system for each method of commanding is shown in Figures 3-9 through 3-11. Full straightening is the control law used.

Figure 3-9 shows that if every conveyer section is commanded, the placement error must be no larger than 0.004 ft. This error is much smaller than can be expected by the placement system and therefore placing each individual section is not feasible. Figures 3-10 and 3-11 show the tolerable system errors for commanding every second and every third conveyer section. These figures show that larger roof support pullup errors can be tolerated when every second and third section is placed. Also, placement errors as large as 0.10 feet (standard deviation) have little effect when pushing every second or third conveyer

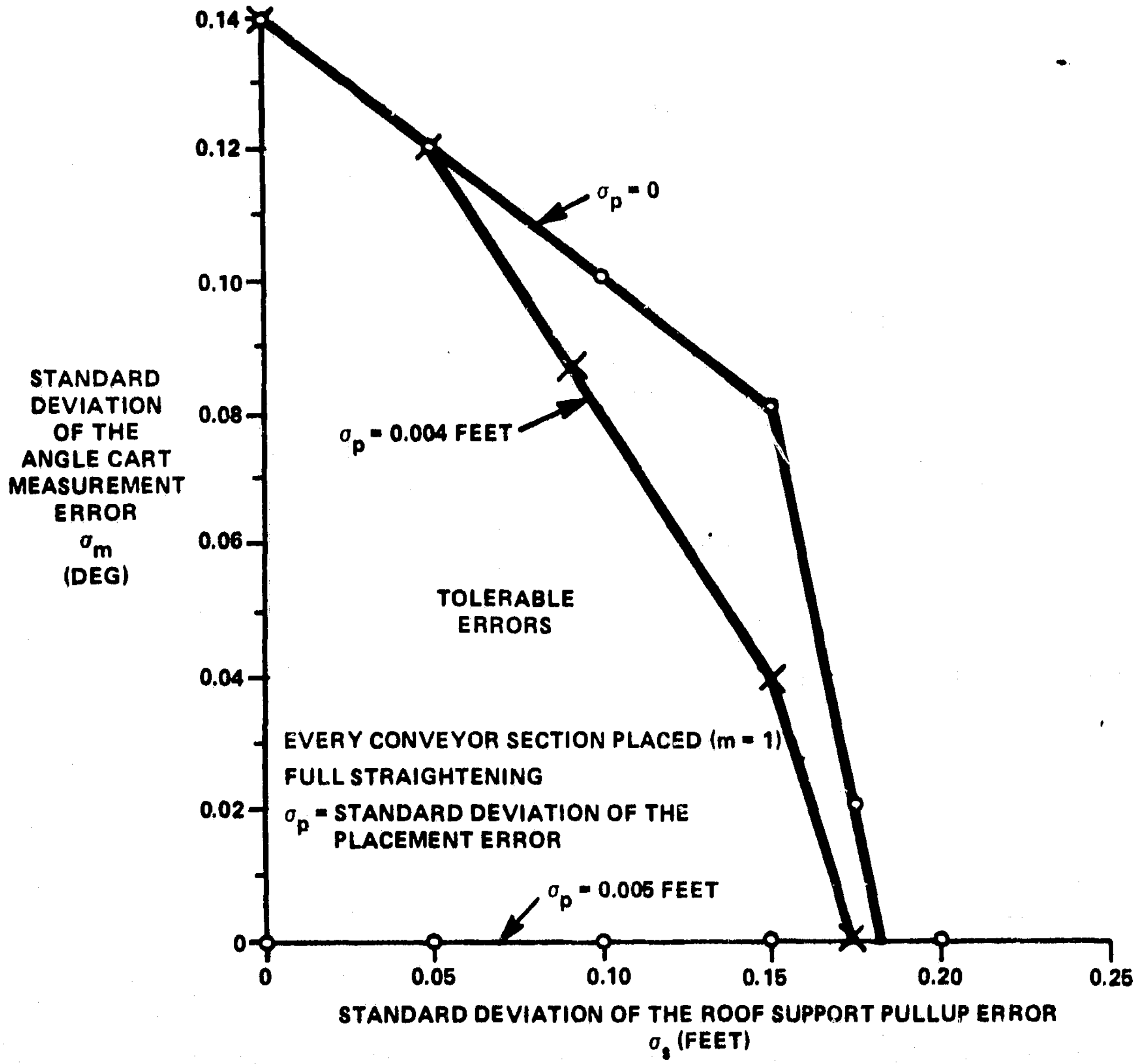


Figure 3-9. Yaw Advancement Simulation Results - Effect of Placing Every Conveyor Section

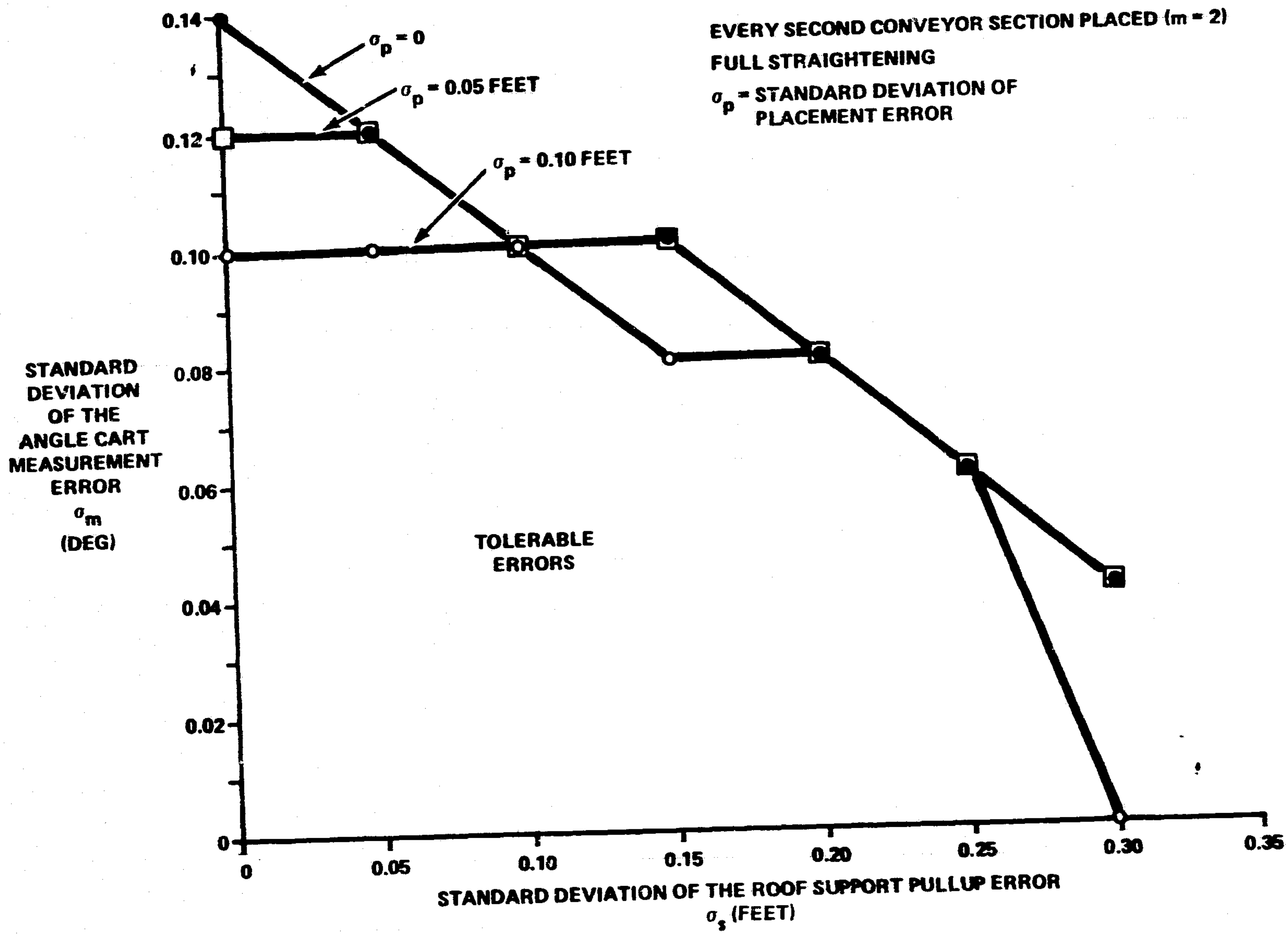


Figure 3-10. Yaw Advancement Simulation Results - Effect of Placing Every Second Conveyor Section

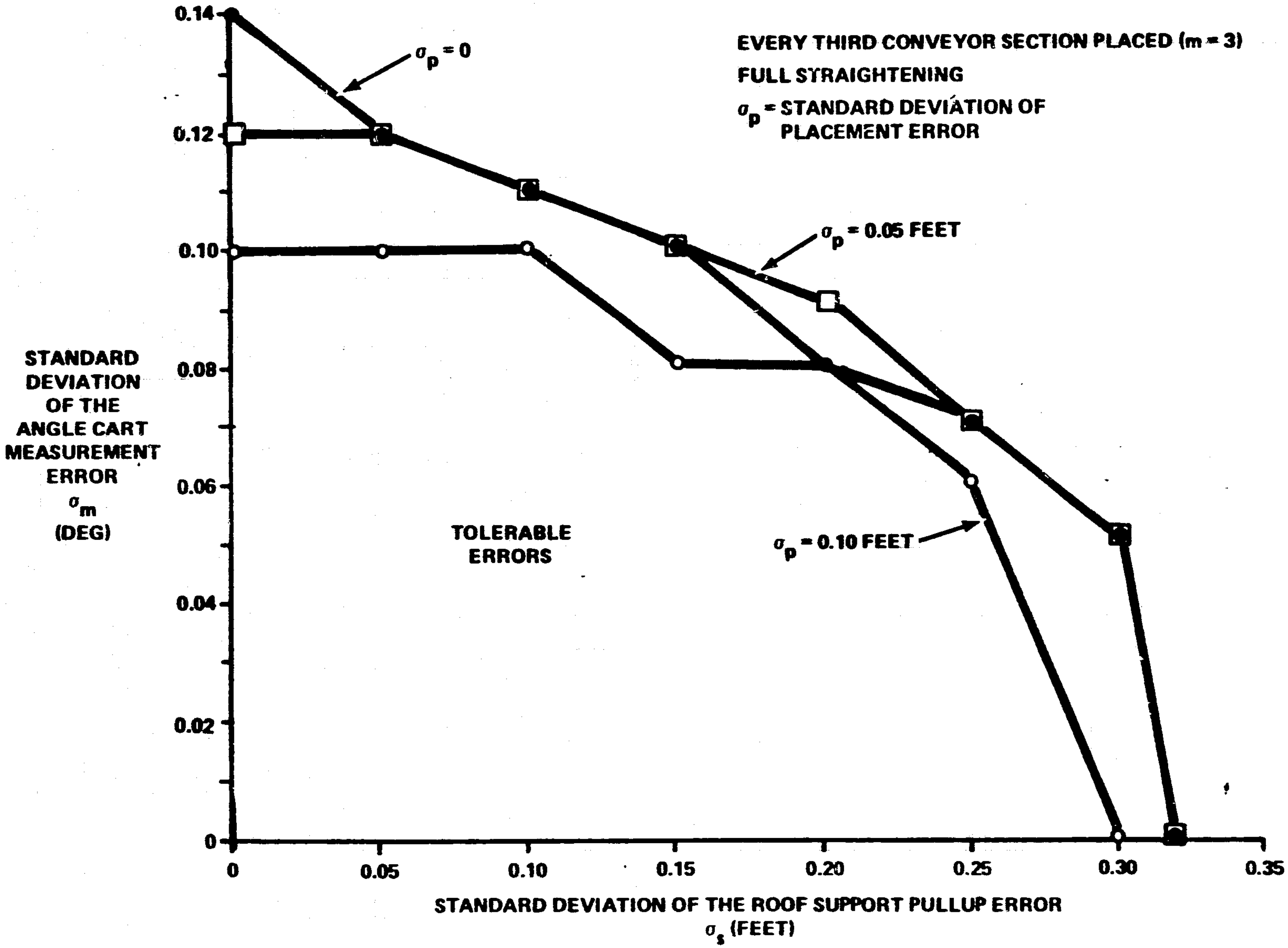


Figure 3-11. Yaw Advancement Simulation Results - Effect of Placing Every Third Conveyor Section

section. The expected accuracy in placing the conveyer is approximately 0.05 feet. The figures also show that the tolerance for system errors is about the same for commanding every second or every third section.

3.4.2 Performance of Yaw Control Laws

Full Straightening

As defined in Section 3.2.2, the Full Straightening control law, straightens the conveyer on each advance. The conveyer section with the least advance is advanced the maximum amount while all the other sections are advanced so the conveyer forms a straight line. The effect of Full Straightening versus No Straightening (no control) on the system efficiency and conveyer askewness is shown in Figure 3-12. The askewness is defined by the maximum amount the conveyer deviates from a straight line, i.e., $\Delta Y = Y_{max} - Y_{min}$. Figure 3-12 was plotted from the results of the yaw advancement simulation after the conveyer was advanced 20 times.

It can be seen that for No Straightening the crookedness of the conveyer increases rapidly with the roof support error. In fact for $\sigma_s > 0.09$ feet the conveyer cannot be advanced 20 times. For Full Straightening, however, the crookedness (after the pullup errors but before straightening) is relatively small. The efficiency for No Straightening is high but for Full Straightening the efficiency drops rapidly with roof support pullup errors. It is clear that a compromise between No Straightening and Full Straightening will improve the performance. Periodic and Partial Straightening is that compromise.

Figure 3-13 and 3-14 show yaw profiles of the conveyer for No Straightening and Full Straightening, respectively.

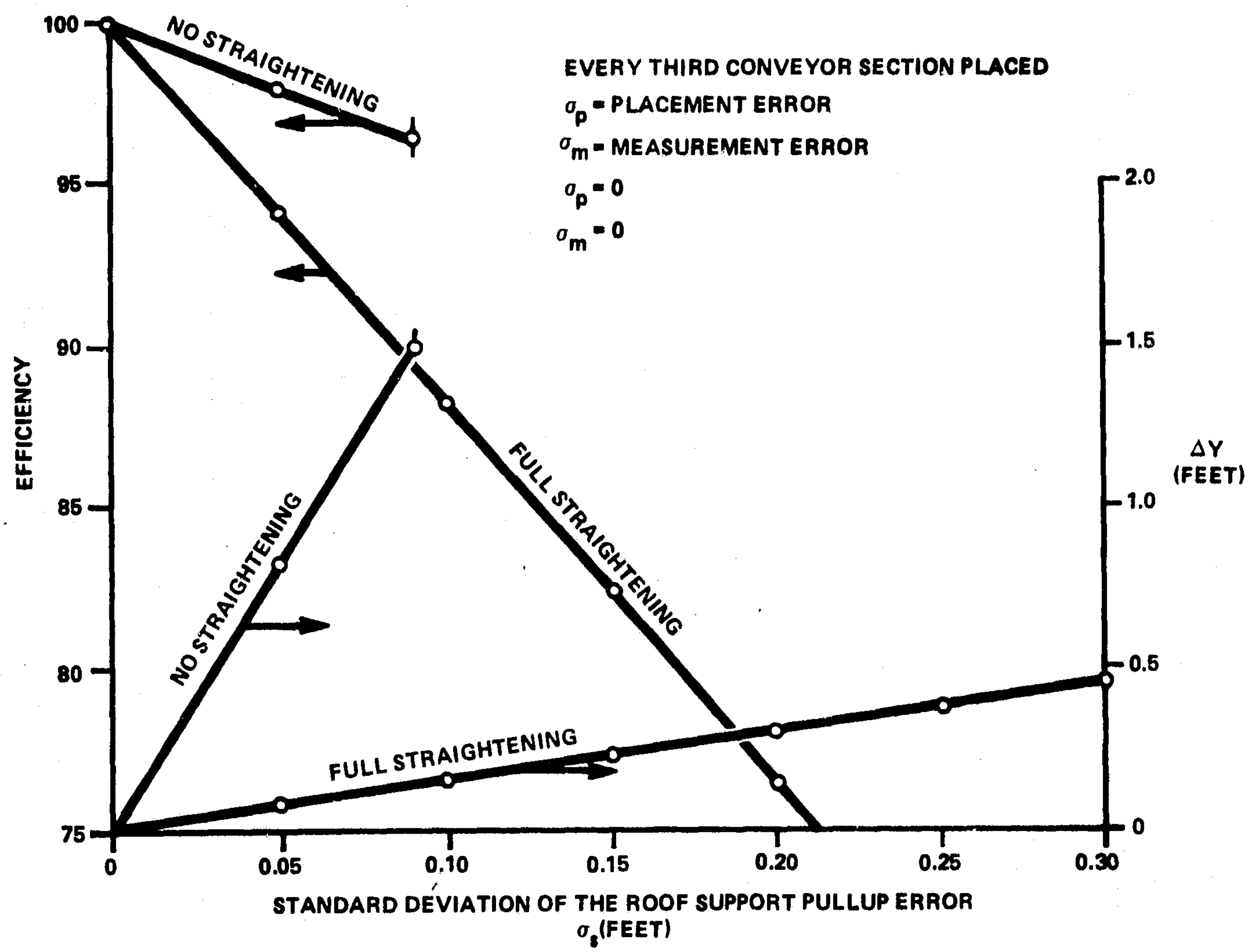


Figure 3-12. Effect of No Straightening and Full Straightening on Efficiency and Askewness

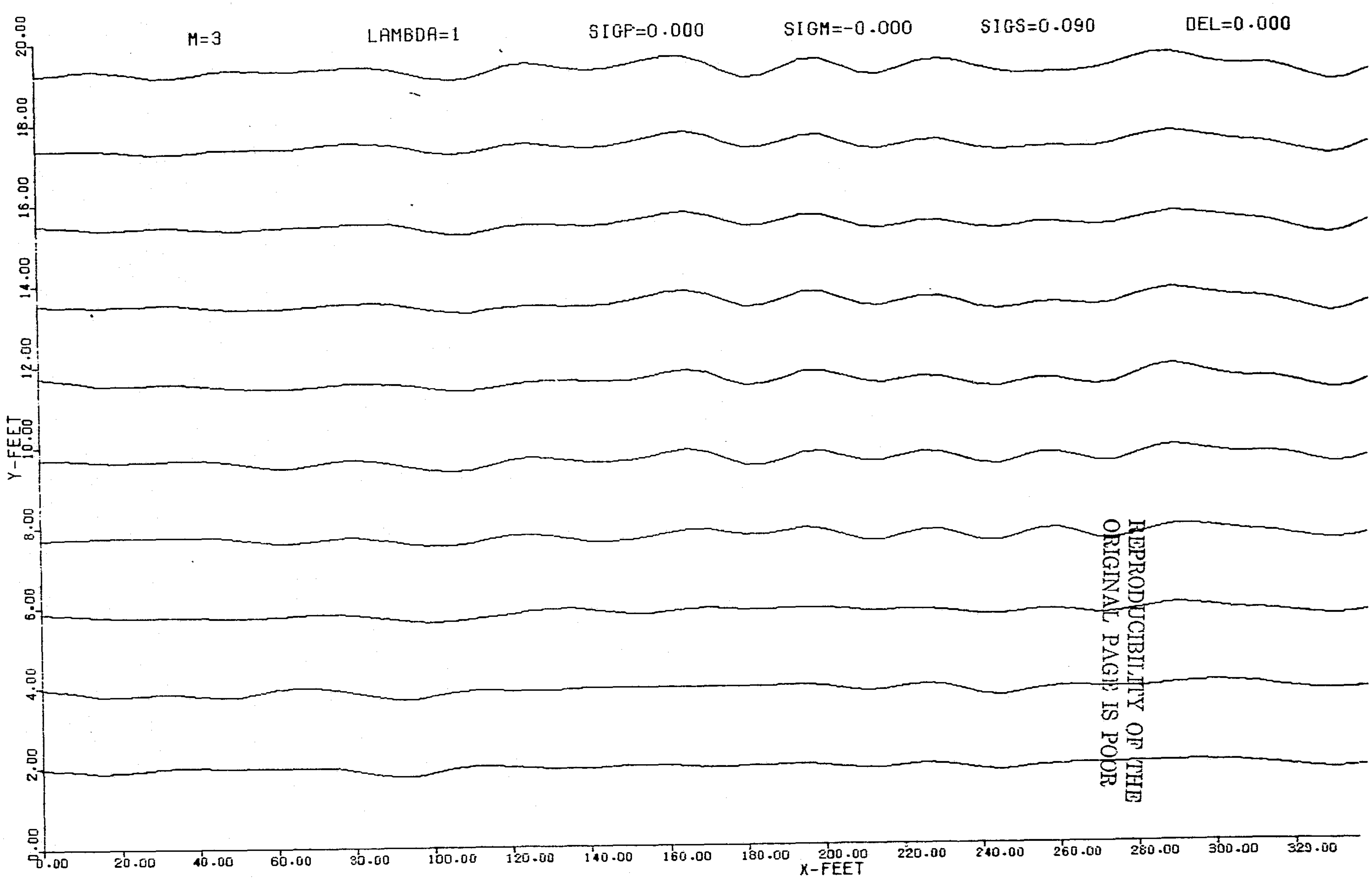


Figure 3-13. Yaw Profiles of Conveyor - No Straightening

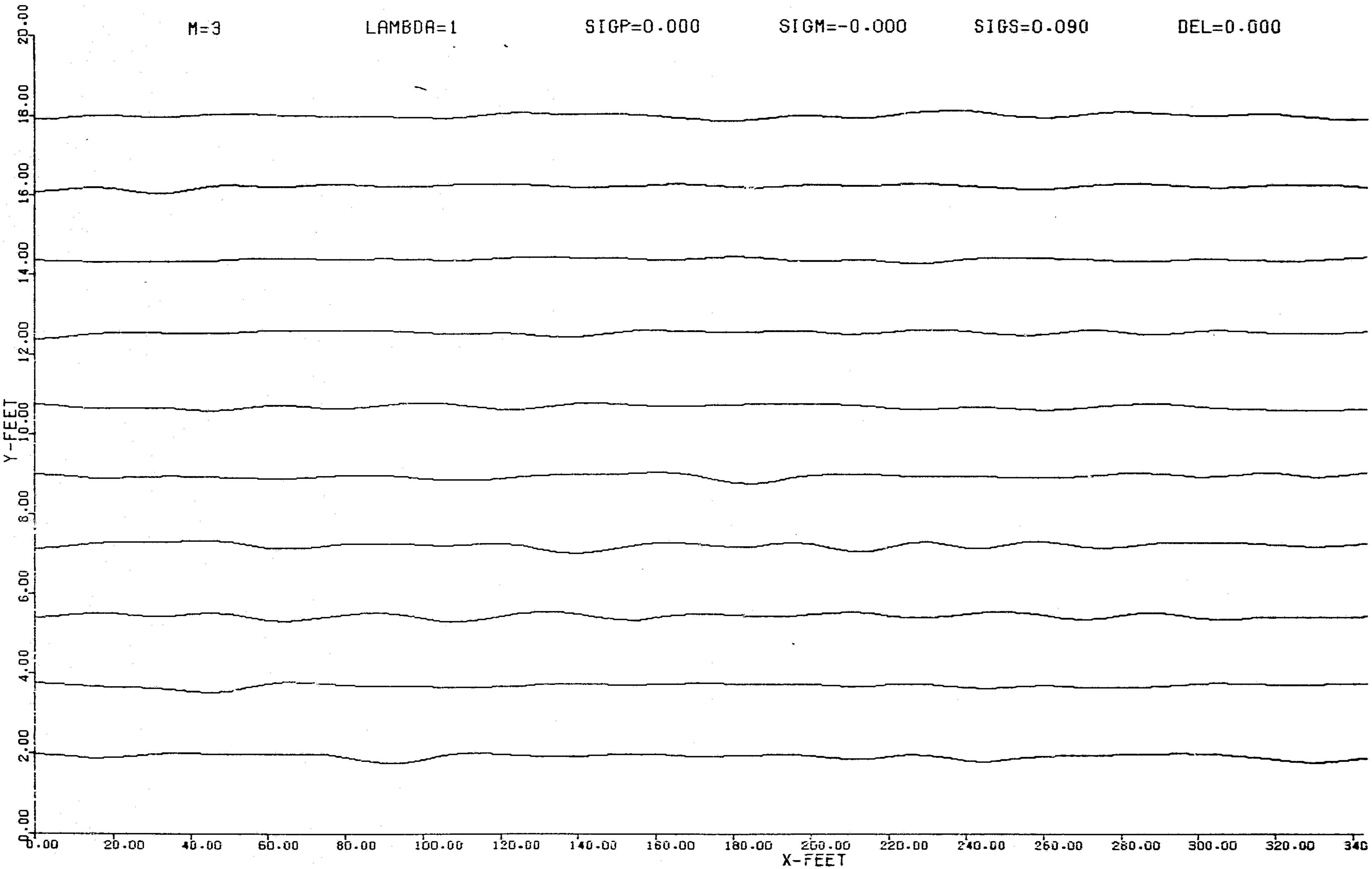


Figure 3-14. Yaw Profiles of Conveyor - Full Straightening

Periodic Straightening

Studies were made to determine the effect on system performance of straightening the conveyer only when it gets crooked by more than a specified amount, i.e., when $\Delta Y > \Delta$, where $\Delta Y = Y_{max} - Y_{min}$. The effect on efficiency is shown in Figure 3-15. The conveyer was straightened whenever it got crooked by more than $\Delta = 0.8$ feet. It can be seen that periodic straightening increases the efficiency by a significant amount. It also demonstrates that larger roof support pullup errors can be tolerated than with No Straightening. The effect on efficiency for a number of values of the parameter Δ is shown in Figure 3-16.

Figures 3-17 and 3-18 show the effect of system errors on performance. In Figure 3-17 the efficiency is plotted versus the measurement error for reasonable and expected placement and roof support pullup errors. Figure 3-18 shows the tolerable system errors for periodic straightening. These results show that periodic straightening when compared to full straightening is equally tolerable to system errors and is considerably more efficient.

Examples of the conveyer yaw profile for Full and Periodic Straightening are shown in Figures 3-19 and 3-20. Reasonable system errors are used. In the Full Straightening figure the conveyer was "straightened" on every advance. In Figure 3-20, the conveyer was straightened only on the sixth and the ninth advances. On other advances the measured $\Delta\hat{Y}$ ($\Delta\hat{Y} = \hat{Y}_{max} - Y_{min}$) was less than 0.8 feet.

It can be seen that the efficiency is better for Periodic Straightening than Full Straightening. Assuming 400 ft coal face, an 8 ft seam, a 2 foot cut and ten advances, Periodic Straightening will cut

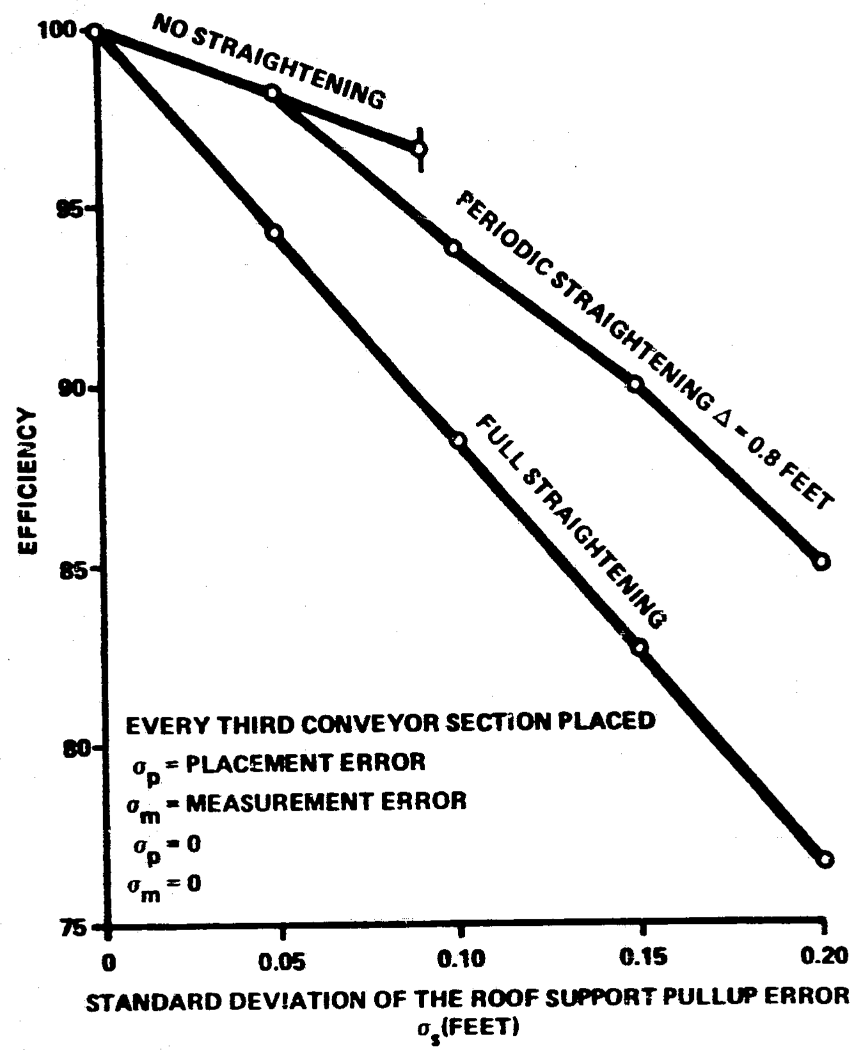


Figure 3-15. Effect of Periodic Straightening on Efficiency

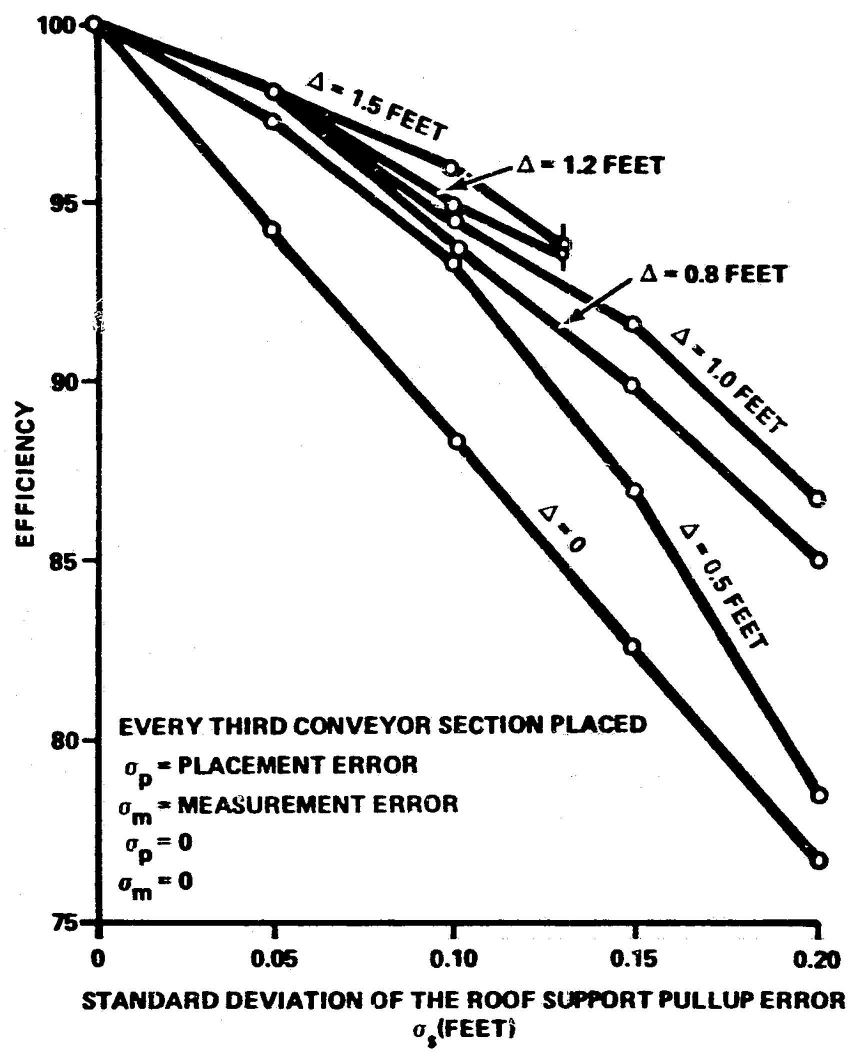


Figure 3-16. Effect of the Periodic Straightening Parameter on Efficiency

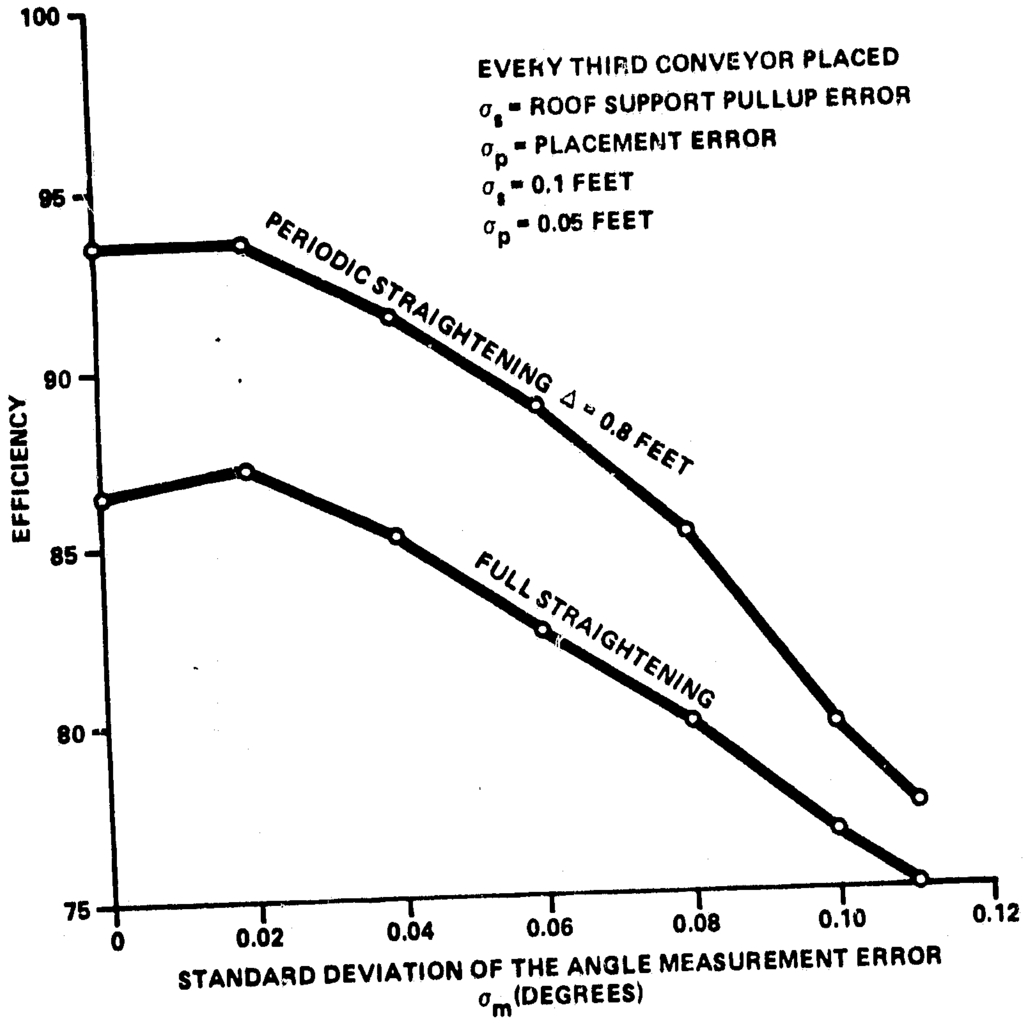


Figure 3-17. Effect of Measurement Error on Efficiency for Full and Periodic Straightening

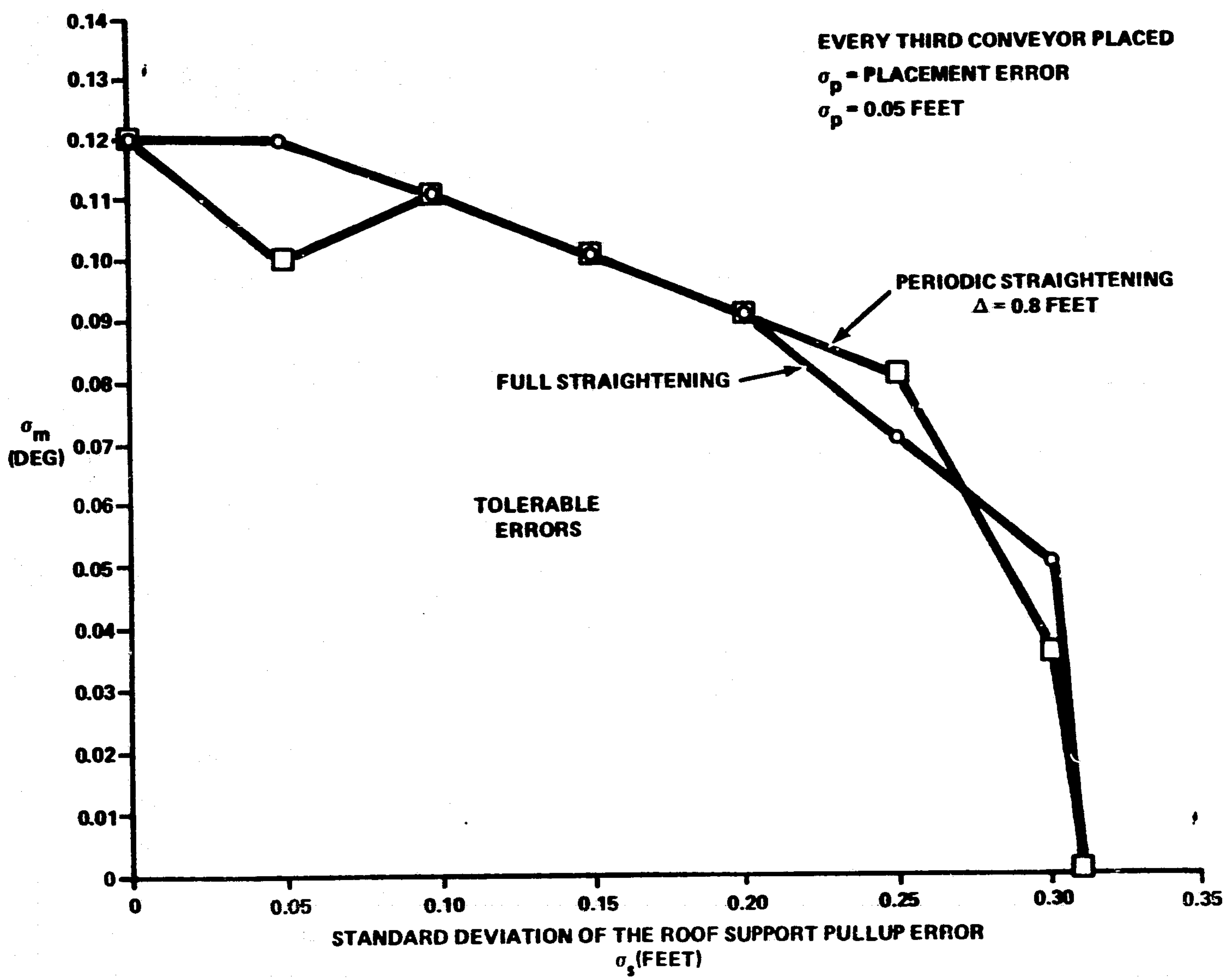


Figure 3-18. Region of Tolerable Errors for Full and Periodic Straightening

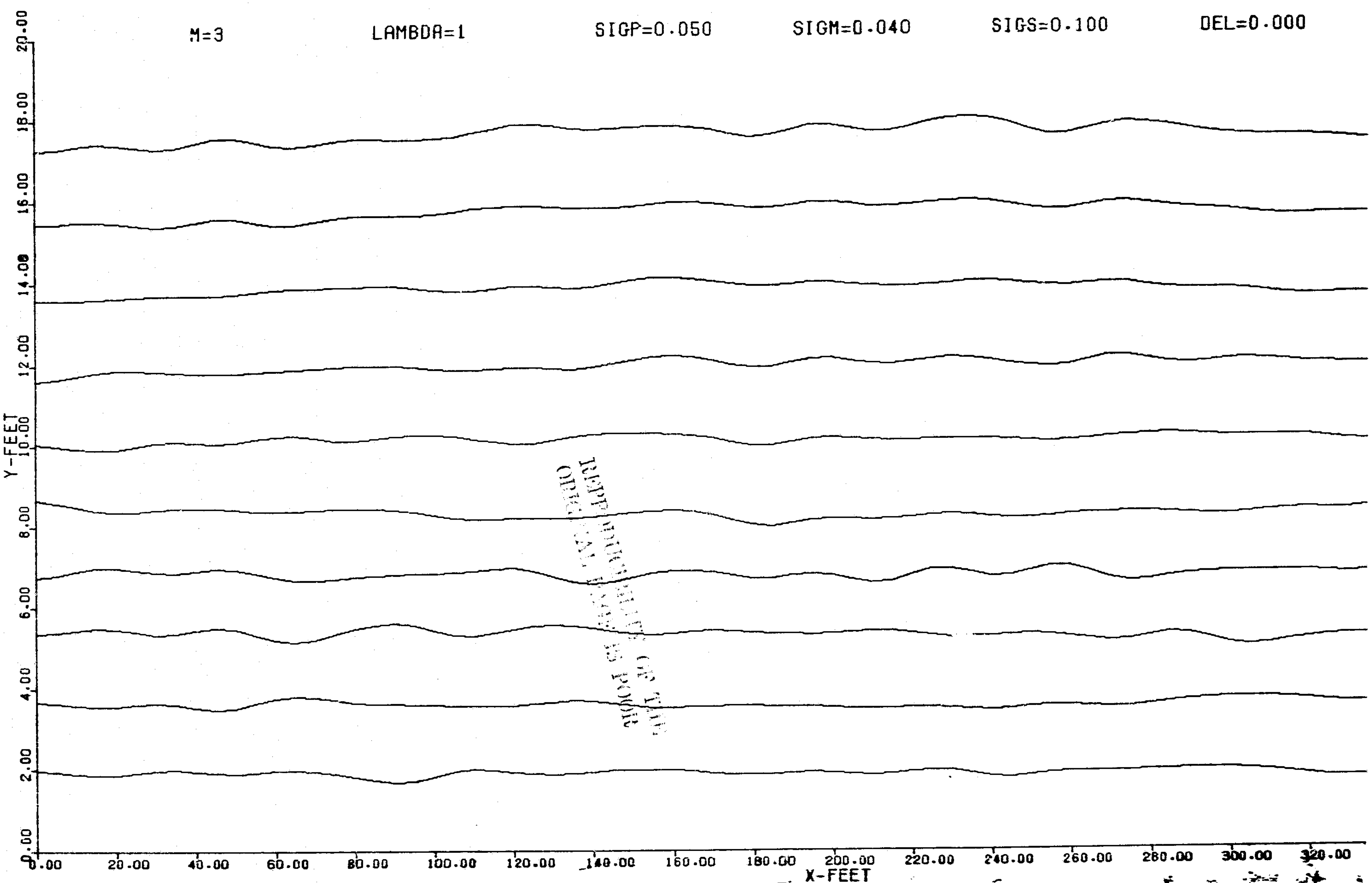


Figure 3-19. Yaw Profiles for Full Straightening

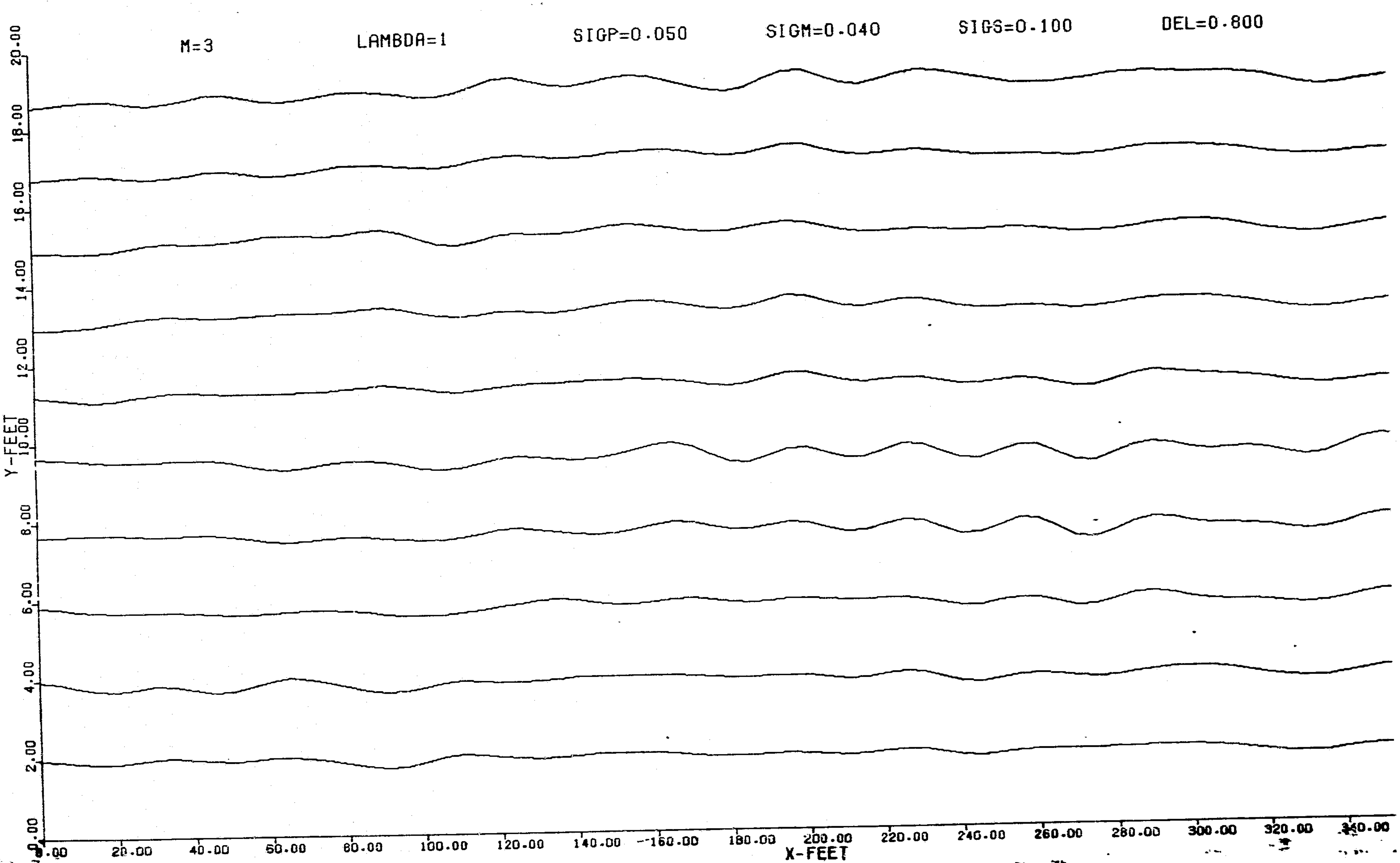


Figure 3-20. Yaw Profiles for Periodic Straightening

160 tons more coal than Full Straightening. This was computed using an efficiency for Full Straightening of 0.85 and for Periodic Straightening of 0.91. The density of the coal was assumed to be 85 lbs/ft^3.

The above results were obtained for irregular periodic straightening, i.e., the straightening (with respect to the advance number) does not occur regularly. A study was also made to determine the effect of regular periodic straightening. In this case the conveyor was Fully Straightened every fifth advance. The results are shown in Figure 3-21. It can be seen that smaller roof-support pullup errors can be tolerated for regular periodic straightening (every fifth advance) than for irregular periodic straightening (Δ = 0.8 feet). If the angle measurements are made with a shearer mounted system, then measurements will be made on every advance and Regular Periodic Straightening is not of interest.

Partial Straightening

As described in Section 3.2.2, Partial Straightening pushes the conveyer section that is furthest back a full stroke but all of the other sections part way between straightening the conveyer and a full stroke. This method of control increases the efficiency while still not allowing the conveyer to get too crooked. The effect of the partial straightening parameter K on the system efficiency is shown in Figure 3-22. The effect of Partial Straightening on the system tolerance to errors is shown in Figure 3-23. It can be seen that much larger measurement errors can be tolerated for Partial Straightening than for Full Straightening. This is because for Partial Straightening the larger measurement errors make the conveyer more crooked but do not tend to place the conveyer behind the previous advance.

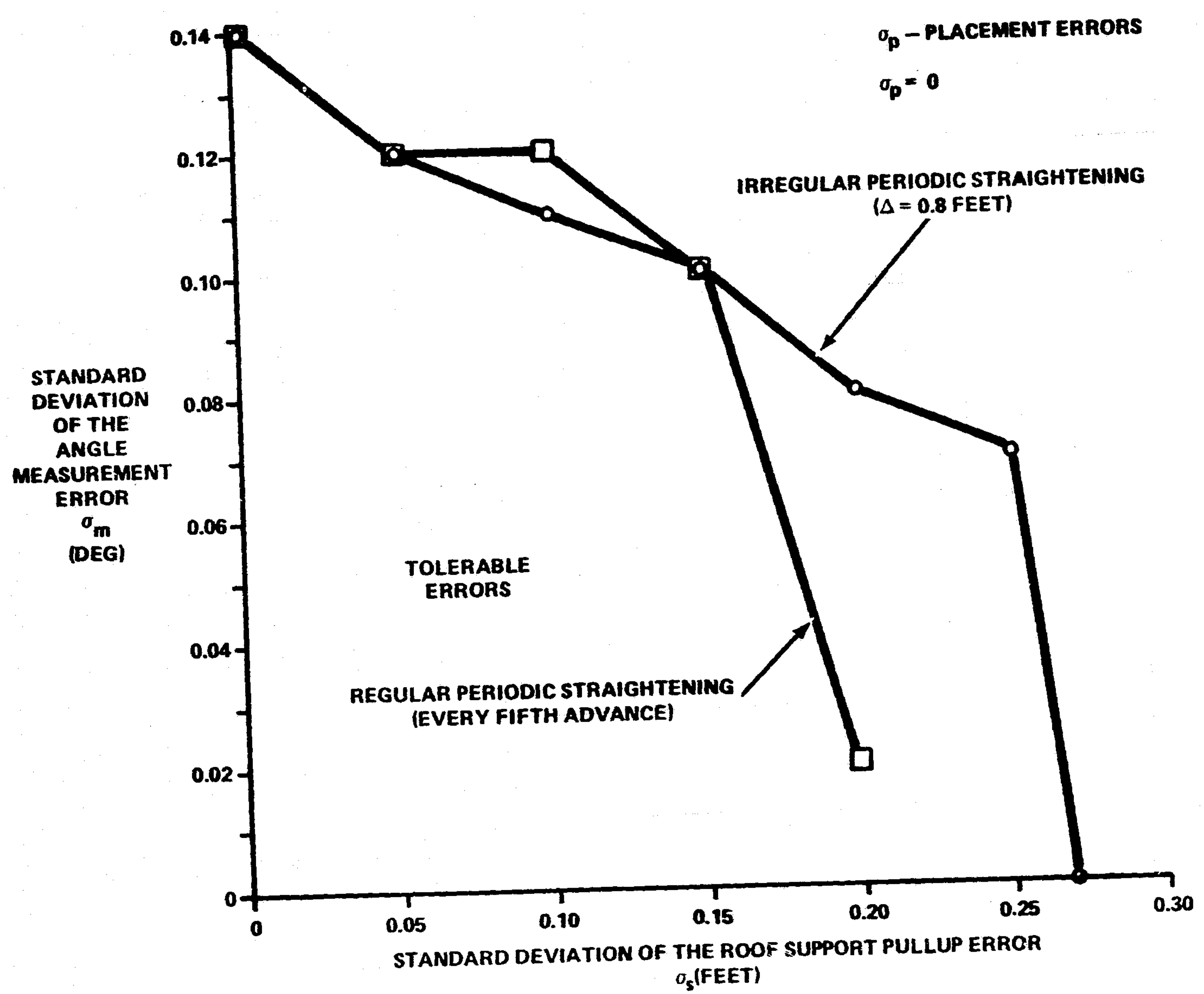


Figure 3-21. Tolerable Errors for Regular and Irregular Periodic Straightening

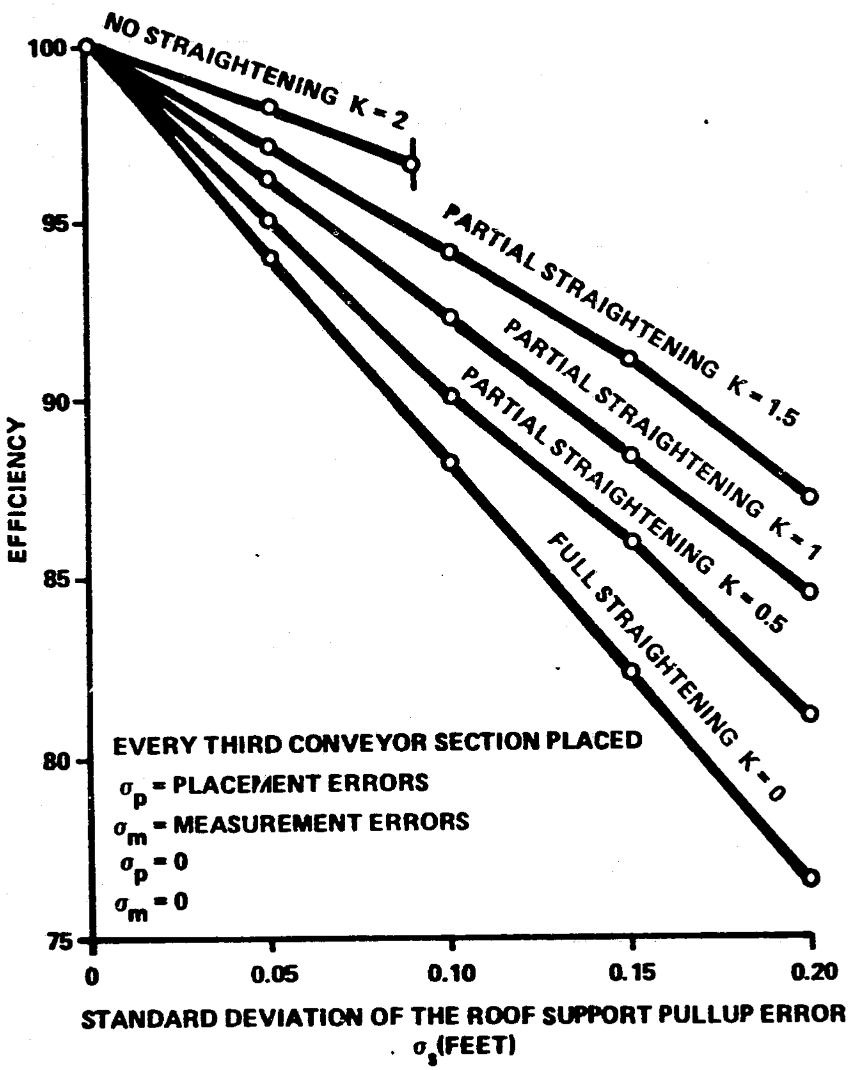


Figure 3-22. Effect of the Partial Straightening Parameter on System Efficiency

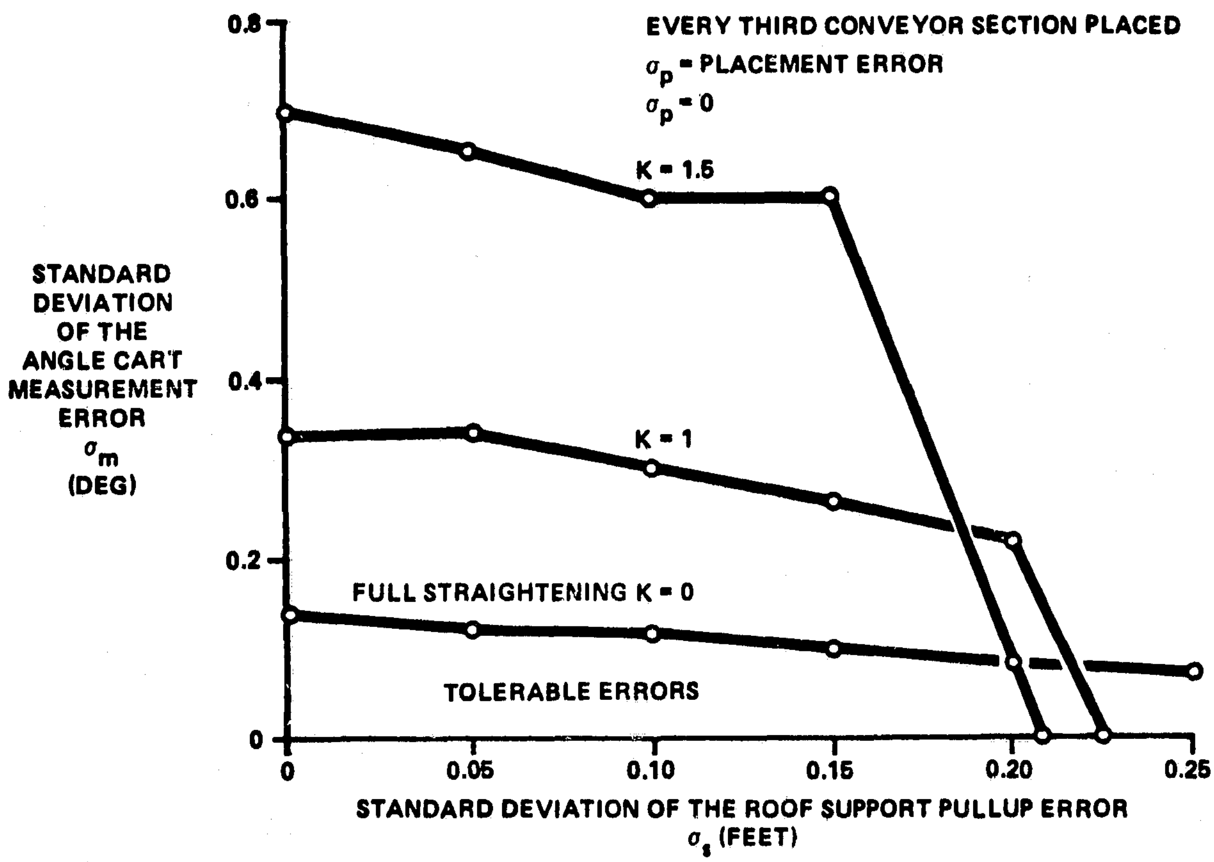


Figure 3-23. Tolerable System Errors as a Function of the Partial Straightening Parameter

The effect of measurement errors on efficiency is shown in Figure 3-24. It can be seen that partial straightening is considerably more efficient than full straightening. Also, it can be seen that measurement errors decrease the efficiency. An efficiency of 90 percent requires measurement error to be less than 0.04 degrees. Figure 3-25 shows yaw profiles for partial straightening (K=1), and reasonable system errors. The efficiency is about 91 percent compared to 85 percent for Full Straightening with the same errors.

Combined Periodic and Partial Straightening

Combined Periodic and Partial Straightening is simply periodically straightening the conveyer whenever it gets crooked by more than a certain amount. When it is straightened it is only partially straightened using the parameter K. The effect on efficiency of combining these control laws is shown in Figure 3-26. This figure shows that an increased system efficiency can be obtained with combined Periodic and Partial Straightening. Figure 3-27 shows the tolerable system errors for the reasonable system placement error of $\sigma_p = 0.05$ feet. It can be seen that an adequate roof support error ($\sigma_s = 0.2$ feet) can be tolerated. Figure 3-28 shows the effect of measurement errors (for various values of the partial straightening parameter) on the efficiency. It can be seen that for K=1 and $\sigma_m = 0.04$ degrees an efficiency near 95 percent is obtained. The yaw profile of ten advances of the conveyer for reasonable system errors is shown in Figure 3-29.

3.4.3 Recommended Yaw Control System

The combined Periodic and Partial Straightening yaw control algorithm is the recommended system to be used with the angle measurements. The system is adequately tolerable to system errors and gives

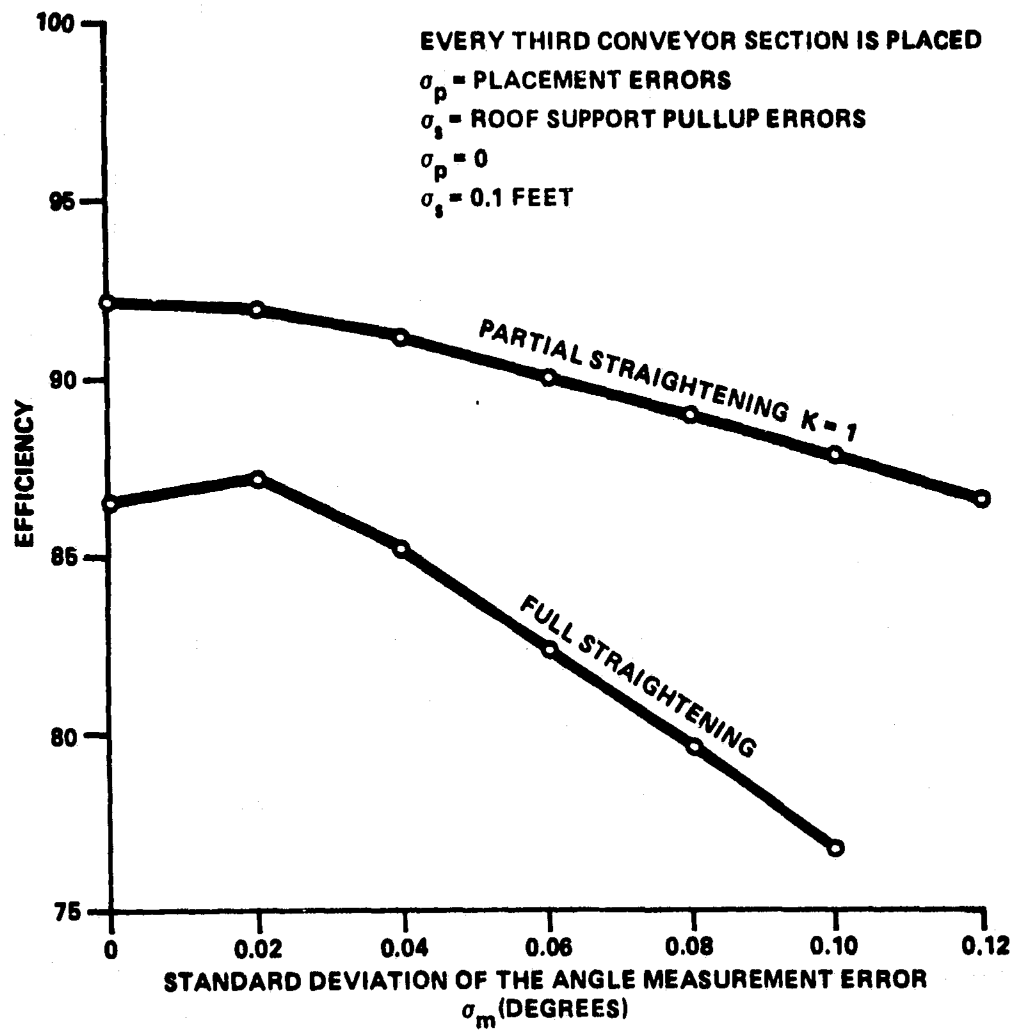


Figure 3-24. Effect Measurement Errors on Efficiency - Full and Partial Straightening

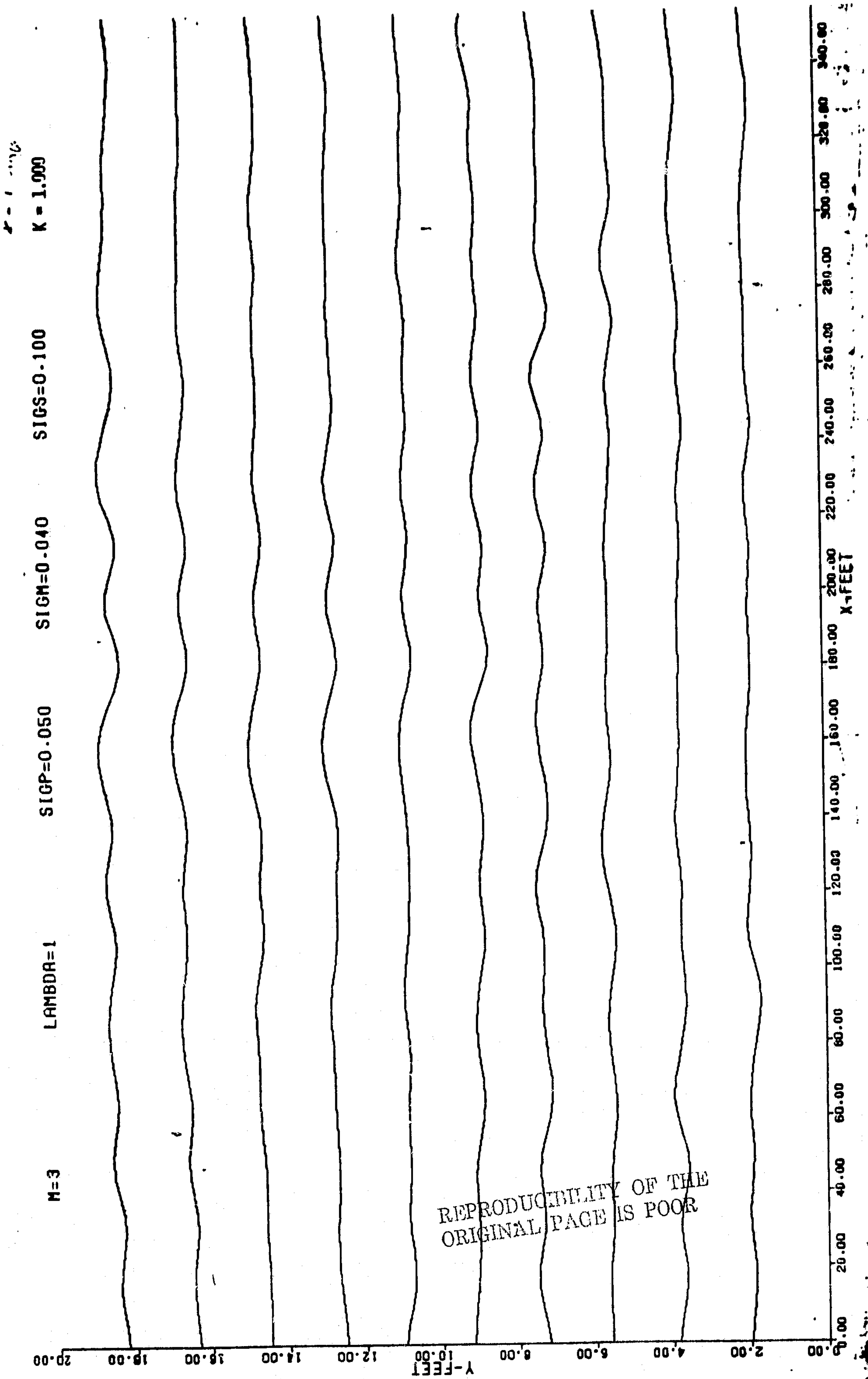


Figure 3-25. Yaw Profiles for Partial Straightening

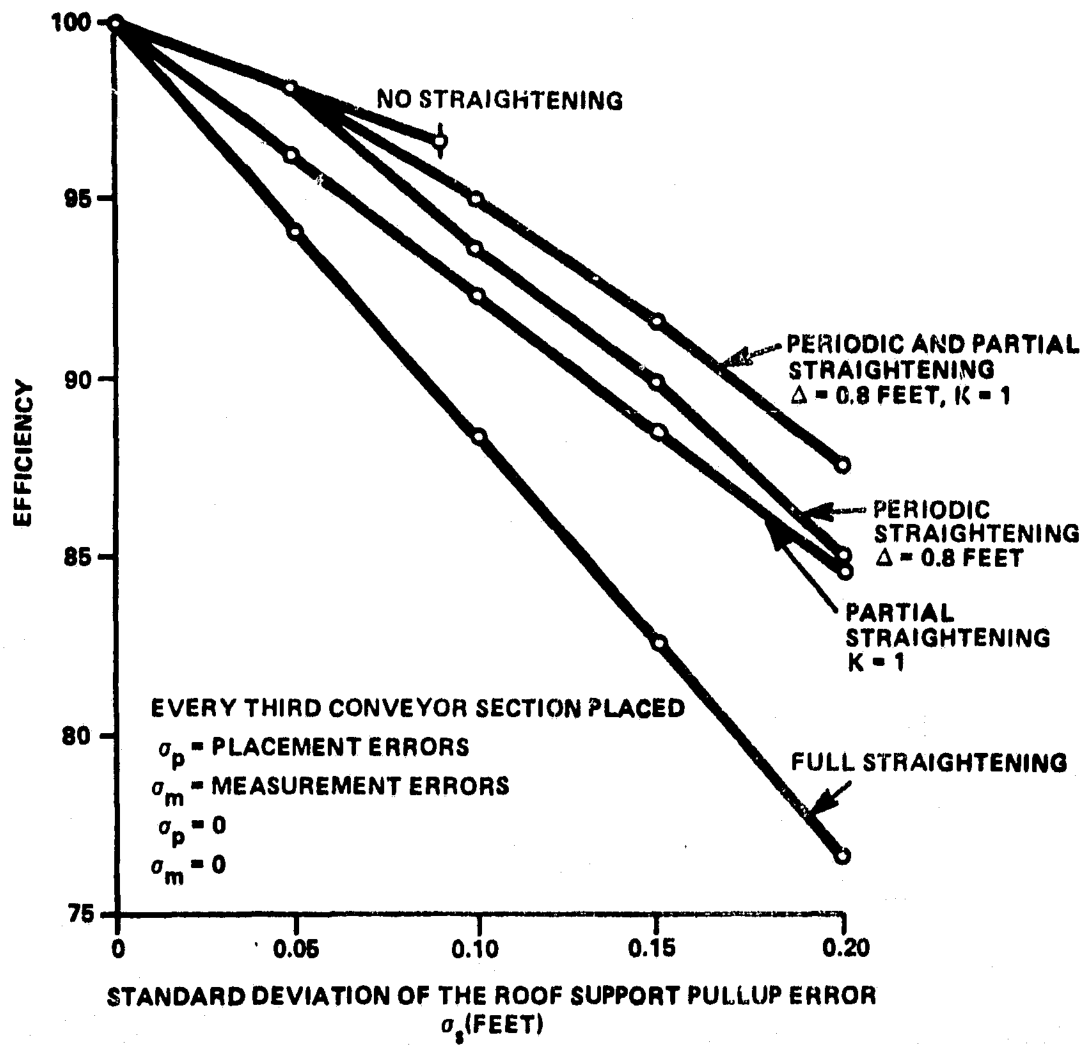


Figure 3-26. Effect of Combined Periodic and Partial Straightening on Efficiency

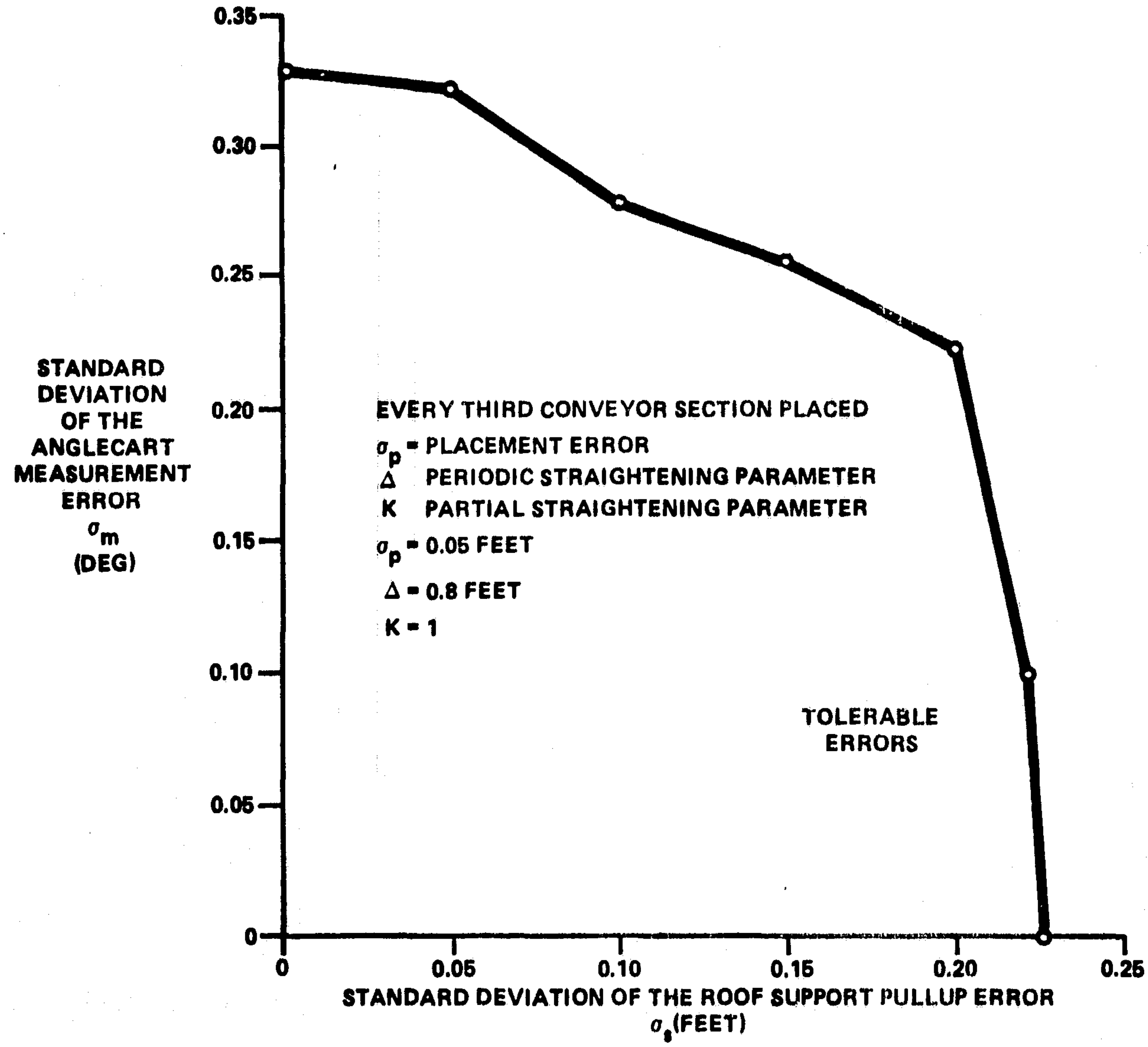


Figure 3-27. Tolerable System Errors for Combined Periodic and Partial Straightening

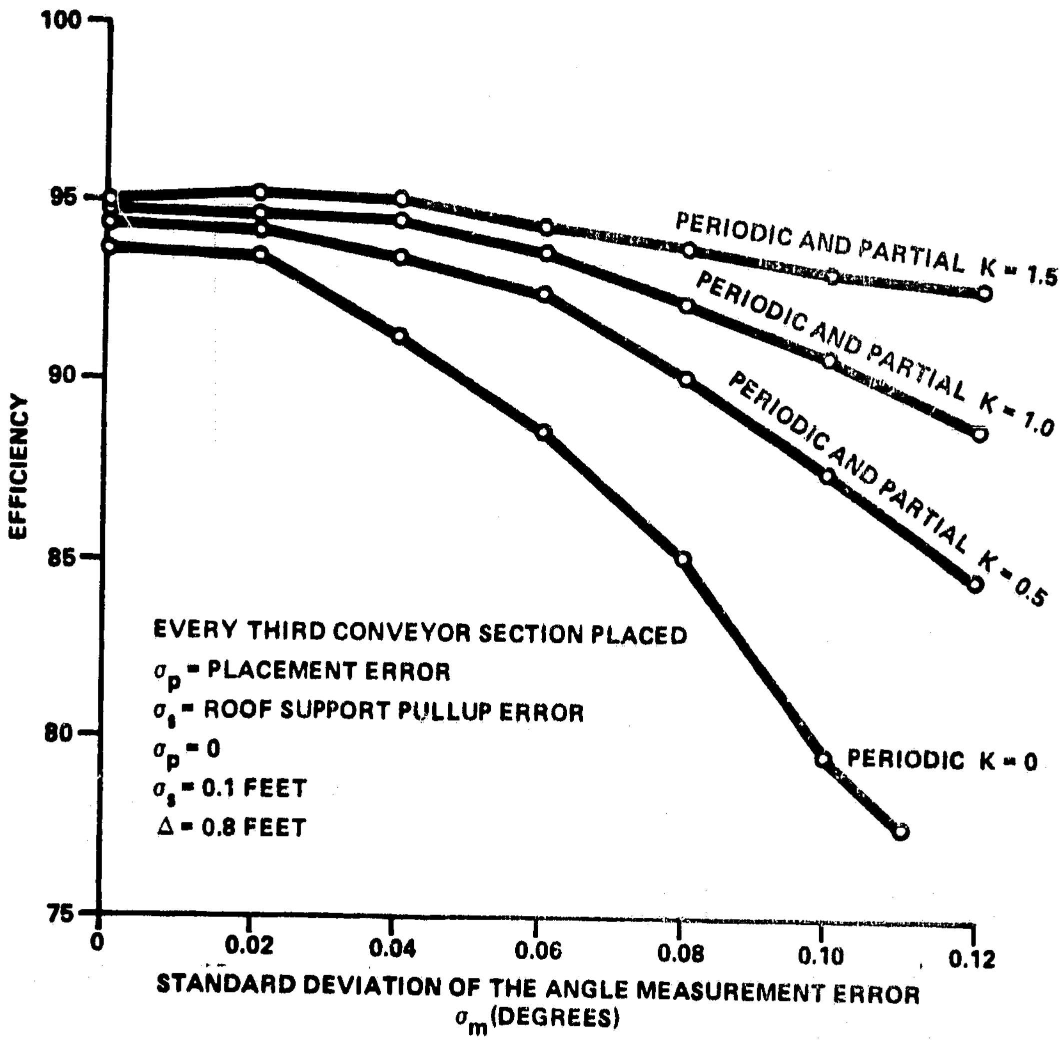


Figure 3-28. Effect of Measurement Errors on System Efficiency - Combined Periodic and Partial Straightening

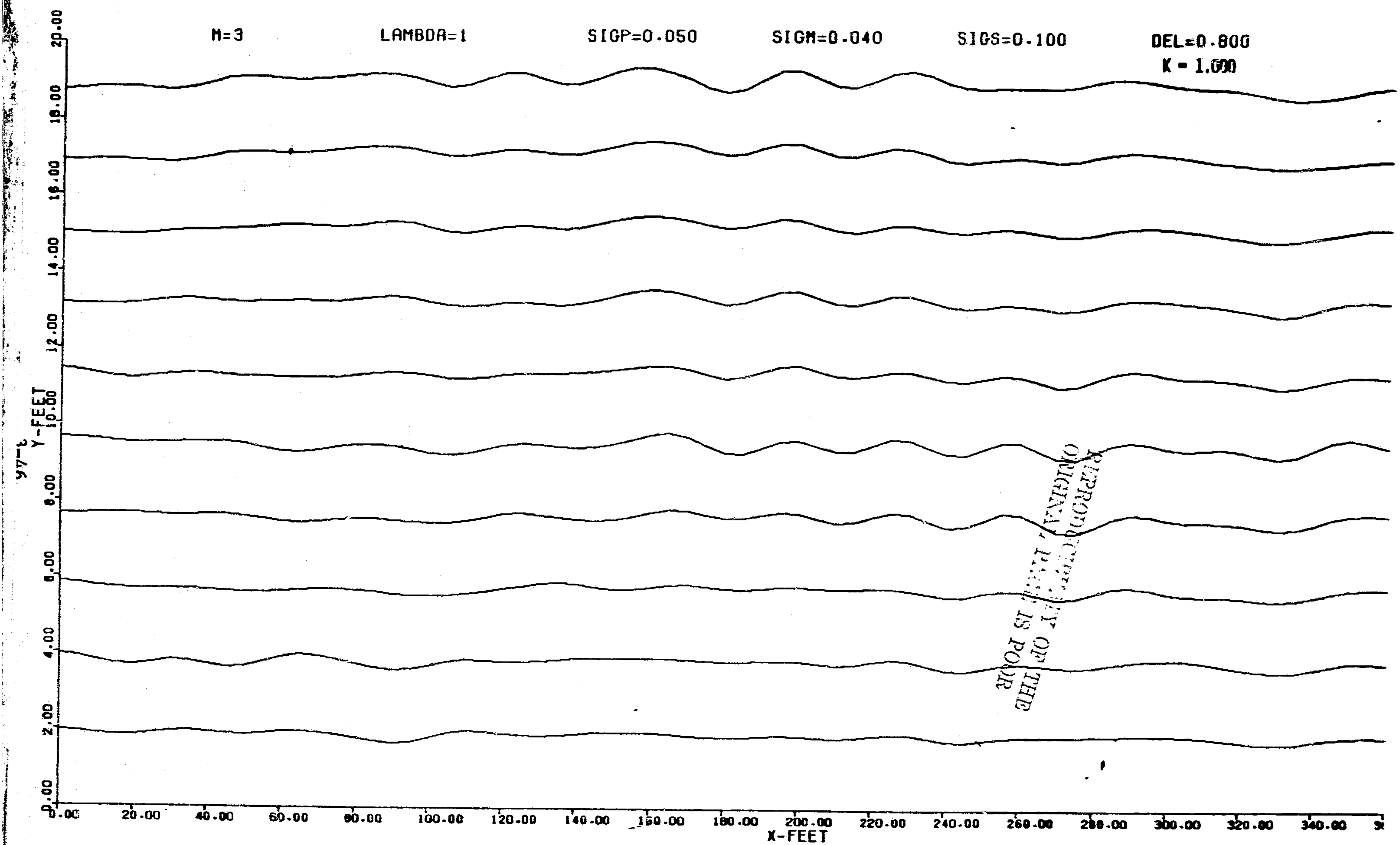


Figure 3-29. Yaw Profiles for Combined Periodic and Partial Straightening

good efficiency. Control parameters of $\Delta = 0.8$ feet and $K=1$ give good performance. Placing every third conveyer section is a viable method of advancing the conveyer.

3.5 CONCLUSIONS AND RECOMMENDATIONS

The yaw alignment system has been developed to automaticaly advance the conveyer and pull up the roof supports, keeping the coal face relatively straight. Angular measurements of the conveyer sections are made so that the conveyer shape (profile) can be computed. Conveyer placement commands are then computed to realign the conveyer. The conveyer placement commands are determined from the control law algorithm.

Previous studies to evaluate the system performance showed that an angle cart type of measurement system can be used to measure the relative angles between the conveyer sections. Mounting such a device on the shearer will allow the measurements to be made on the clean-up pass. Present studies indicate that pushing every third conveyer section will give adequate performance. A control algorithm that periodically and partially straightens the conveyer will achieve superior performance to fully straightening the conveyer of every advance. The efficiency is very good (95 percent) and is highly tolerant to system errors. System errors of the expected magnitude can easily be tolerated.

4. YAW ALIGNMENT SYSTEM DESIGN

The yaw alignment system is designed to operate in the fully automatic mode. When the shearer comes to the end of a pass, and goes to the manual mode as a machine sequence step for executing the turn around maneuver, the microprocessor in the ECM calculates the new alignment profile required by the mining method. This data is then sent to the roof supports according to the roof support management algorithm being used. After the turn around sequence, when the system is returned to the automatic mode, by depressing the automatic mode on the Master Control Station, the required roof support algorithum is executed. The shearer then illuminates the ready light to indicate that all is ready to traverse the face. The shearer pass may then be started by advancing the haulage rate to the desired speed.

The mining method is selectable by firmware programming. Either the half face sump or the full face sump mining method may be selected for operation. If one method is selected and it becomes necessary to change to the other a new firmware memory device, programmable read only memory (PROM), must be installed in the system.

The cleanup pass, if required, may be performed by the operator at the Master Control Station (MCS) in the remote mode of operation. To initiate the cleanup pass it is necessary to configure the shearer to the cleanup mode, drums down, and to run the shearer down the face in the remote mode of operation. If a cleanup pass is required in automatic mode it is necessary to depress the clean up button at the MCS to initiate such operation on the next pass of the shearer down the face.

The individual roof supports may be exercised from the MCS by the use of the Display Address System (DAS) control and other indicators and controls provided. Control of the face conveyor configuration and the roof in the adjacent area is done by the roof supports operating in the automatic mode. The remote mode of operation of

these supports is provided for maintence and convenience only - it is not expected that any great degree of control may be exercised over the face conveyor profile, as a whole, by the use of these controls on individual roof supports.

For either the full face sump or the half face sump the basic design intent is to maintain all roof supports in the fully advanced condition; ie: up against the face conveyor, when the shearer traverses on the cutting pass. This is readily accomplished in all parts of the face conveyor except that area near the snake. In the snake region it is probable that several roof supports will be positioned with their horizontal rams partially or fully extended. This approach is taken because it is desired to minimize faulty roof support operation due to debris in the region between roof support and face conveyor. Advancing the roof supports as soon as possible will minimize the incidence of minor roof falls which would otherwise be present if they were not pulled up.

At the end of a pass, during turnaround sequencing, the roof supports interact with the roof support management algorithm selected and position themselves so as to satisfy the calculated yaw alignment criteria. In the event that a failure occurs either through equipment malfunction, debris or other environmental problem the system will go to the "halt" state, illuminate the "hold" indicator and await operator intervention. The operator may then interrogate the equipment by use of the DAS panel on the display console. Many equipment failures may simply be over-ridden by the operator to allow system operation to proceed until maintenance time is available to routinely deal with the problem. Some malfunctions of individual roof supports may be prevented from impacting system operation by simply switching to the alternate positioning algorithm. Some malfunctions will undoubtedly require manual intervention at the location of the malfunctioning roof supports.

All roof support equipment is monitored by the microprocessor located on the shearer on a time shared sequential basis. Potential failures which can cause a catastrophic breakdown will be detected and reported to the MCS. Those system failures which might interact to cause a shearer breakdown will be detected and will initiate a "SHRDON" condition. The system will then await operator intervention.

4.1 Overall Design Considerations for Yaw Alignment System

The yaw alignment system implemented herein is designed to optimize coal production on the face. This is best accomplished (see Section 3.0 System Analysis) by using a partial periodic straigntening technique - not by keeping the face conveyor maximally straight. The amount of correction to introduce into a crooked face conveyor and the criteria to be used to assess the need for any correction at all are front panel parameters that must be entered via the MCS by the operator prior to going to the automatic mode. As a part of the straightening algorithm in the yaw control system, the angle cart correction data is read and the resulting crookedness is limit checked to determine if a correction is necessary. If straightening is determined to be necessary the straightness digit switch is used as a parametric input to the straightness calculation.

Headgate and tailgate displacements from survey stakes, in inches, must be put into the system when the shearer is at one of its end conditions ready for a straightening operation. These are required parameters and must be entered after each pass.

In the matter of moving face conveyor sections by extending the horizantal rams from load bearing roof supports, the method selected is to move horizantal rams on every third roof support while allowing the horizantal rams on all other roof supports to be unlocked and able to track. This method produces good face conveyor placement without stressing the members or requiring unreasonable mechanical and measurement tolerences. Because of this "every third

roof support" approach, there exists three separate groups of roof supports, independent from each other, that can serve as the active group in the face conveyor placement algorithm. A rotary switch on the front panel of the MCS is used to select which of the three groups is used according to the following definition:

Group 1   1 - 4 - 7 - 10 . . . . (N-2)

Group 2   2 - 5 - 8 - 11 . . . . (N-1)

Group 3   3 - 6 - 9 - 12 . . . . (N)

All of the parameters that are required for entry are required for the system algorithm and are not related to an individual section or roof support.

4.1.1 Face Conveyor Yaw Alignment - Face Conveyor advance commands are generated by the ECM microprocessor on the basis of angle cart measurements and conveyor snaking requirements. Raw data from the angle cart is sampled in memory as the shearer proceeds down the face on a straight (No Sump) cut. This data is then processed to obtain deviations from the ideal profile as a function of down face location. The data thus obtained is algebraically added to the advance requirement of the mining method algorithm to provide a table of advance distances for the roof supports horizontal rams.

During the turnaround sequence this table of advance distances is transmitted to the roof supports so that each roof support storage register contains a distance dimension for its horizontal ram motion. After all of this data is received by all of the roof supports, execute move commands are sent to certain of the roof supports according to one of the three possible positioning algorithms. This causes the selected roof supports to move the face conveyor and the non-selected roof support horizontal rams to be extended by the motion of the face conveyor.

4.1.2 Roof Support Pullup Sequencing - Immediately after positioning of the face conveyor and simultaneous with initiating the shearer traverse, all of those roof supports whose horizontal ram is extended along the straight protion of the face conveyor are commanded to sequence forward to the face conveyor. The control algorithm that sequences the roof support forward does so in such a manner that a pattern of three well separated roof supports unload from the roof at a time and only those three horizontal rams unlock at a time. Any failure in this sequence will cause a halt to occur and the "Hold" indicator on the control panel will be illuminated. A careful consideration of the half face sump mining method used to illustrate this report reveals that the basic requirement for pulling up the roof supports is that the roof supports that require pull up are always at the opposite end of the snake region from the shearer. The sequence of events shown in Figure 4-1, while not exhaustive, is sufficient to illustrate that this fact is independent of whether or not a cleanup pass is used. The effect of using a cleanup pass is to reverse the "sump-cut-straighten-cut-sump" sequence of events with respect to the starting point of the sequence. A similar pattern of events characterizes the full face sump mining method. Should the system be programmed to manage roof supports and calculate YAW correction data for the full face sump rather than the half face sump the relationship between moving roof supports and the moving shearer would still preclude the possibility that they would move on closely adjacent portions of the face conveyor. The effect of optional use of the cleanup pass is identical; it simply reverses the pattern of events from the initial condition of the sequence.

This dynamic condition allows the shearer to begin the traverse of that portion of the face conveyor between its initial position and the snake and allows the roof supports to position themselves on that portion of the face conveyor beyond the snake. Worst case dynamics estimates based on maximum haulage speed and minimum roof

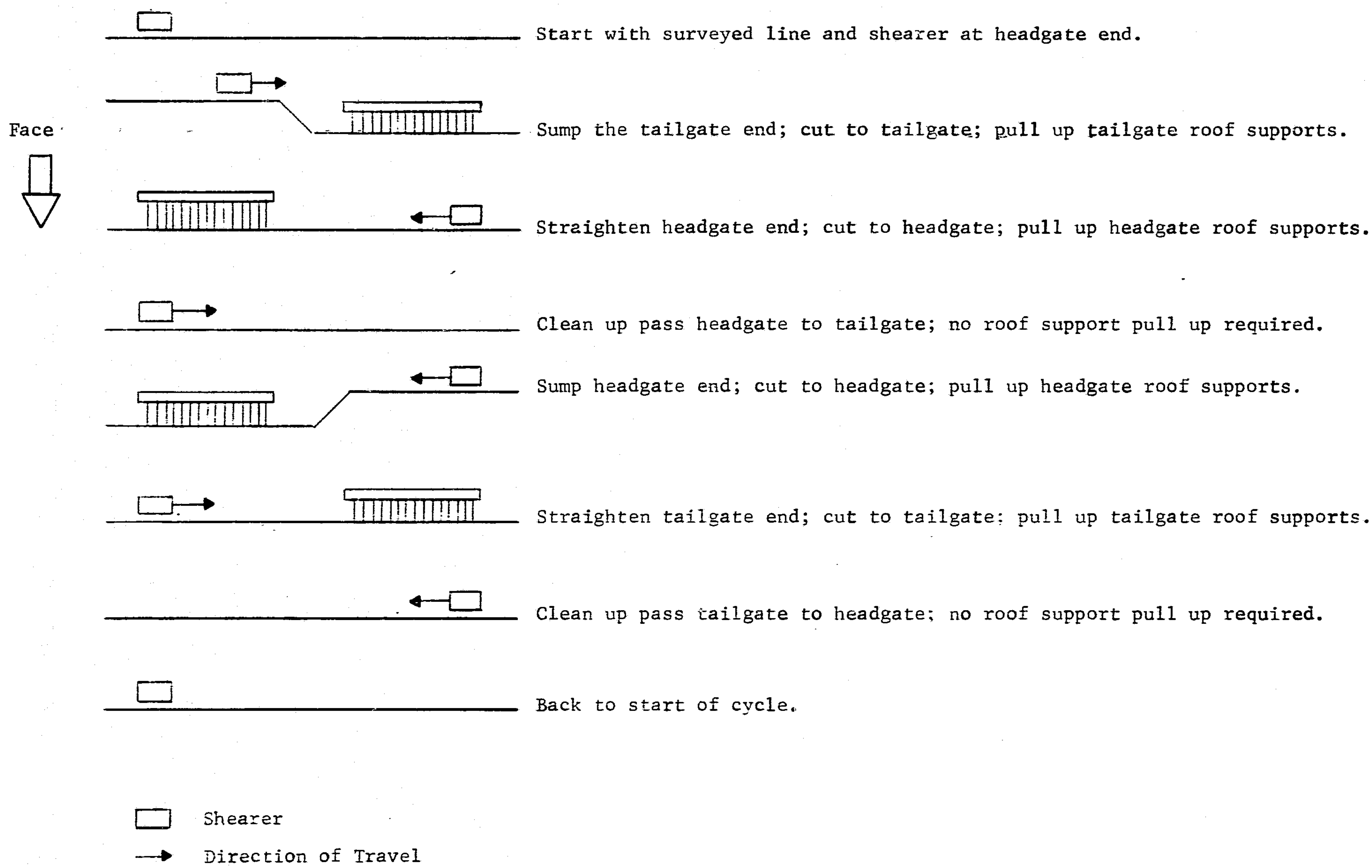


Figure 4-1. Typical Pullup Sequence Diagram

support positioning speed make it clear that, while the roof supports are being positioned ahead of the shearer, the shearer can never approach a moving roof support. In the event that the last roof support has not completed its move before the shearer enters the roof support moving region (beyond the snake), the shear will stop at the snake region and await the move complete statement from the last roof support. At its maximum rate of travel the shearer velocity will be .83 ft/sec (50'/min). And it will take 5.6 minutes to reach the snaked region of the face conveyor from the headgate or tailgate end of a 600' face. If the roof support pullup starts at the same time, all roof supports must complete their move in less than the available 5.6 minutes. The worst condition is a straightening condition where approximately 80 roof supports must be pulled up before the shearer reaches the snake region, pull up time is (worst case) about 12 seconds. If they are sequenced forward one at a time the operation would take 16 minutes and the shearer would have to wait at the snake region for over 10 minutes. This is an unacceptable amount of wait time for the shearer. By sequencing three, well separated roof supports at a time, the last roof support will complete its positioning 5.3 minutes after the shearer starts its traverse and twenty seconds before the shearer expects the position complete signal. These are worst case numbers; the probable timing will allow considerably more than 20 seconds of guard band for this operation. This fail-safe technique for overlapping shearer cutting time with roof support positioning time substantially improves the coal winning efficiency of the system by eliminating the wait requirement on the shearer.

Although not presented in this report, an analogous condition exists for the mining condition that utilizes the full face sump rather than the half face sump described. The dynamics of machine motion is such that the shearer will, most of the time, be cutting past a stationary roof support in the pulled up condition. At no time will the shearer ever be allowed to approach a moving roof support.

The advantage of coal winning efficiency to be obtained by this overlap appears to be even more attractive for the full face sump than for the half face sump.

4.1.3 Recalibration of YAS Alignment System - Power failures or mode changes that are introduced into a Yaw Alignment System that is operating in the automatic mode may cause the working memory intermediate storage to falsely represent the recent previous history of the Roof Support System. Power failures, specifically, will always cause this condition. When it occurs the Yaw Alighment System must be recalibrated.

Recalibration, when required, may be initiated at any point in the operational sequence. If initiated during a pass down the face, possibly because of a random power down condition, The shearer must go to the end of the pass that was in operation and then respond to the calibration request. When it arrives at the headgate or tailgate to perform the calibration pass, the shearer will initate a traverse of the face and read and process angle cart data as it goes. When it arrives at the far end of the Calibration pass it will go through the Yaw alignment calculation. If the calculation finds the face conveyor sufficiently straight then the calibration is complete, the system will sump the face conveyor and the operation will resume. If the calculation determines that the face conveyor is not sufficiently straight, i.e.: possibly sumped already, the system will perform a partial periodic straightening and normal operation will resume. Note that for purposes of calibration a sumped face conveyor is simply considered as a crooked face conveyor and the subsequent correction will be to straighten it; also a straight face conveyor, when determined by calibration run, will cause sumping commands to be issued after calibration. The system thus has a substantial ability to be self correcting for power loss or random interruptions due to mode change.

The recalibration cycle does, as shown, require a calibration pass along the face. This pass may or may not cut coal, i.e.: it may be a cleanup pass over previously cut area. Since the possibility exists that a recalibration is not required the matter is left to operator judgement. Thus, a mode change, which admits the possibility of a moved roof support need result in recalibration only if the operator requests it because a roof support was in fact moved. If recalibration is not requested the system assumes that its data bank contains current accurate information relative to face conveyor alignment and roof support position. In the event of power failure this memory is lost and recalibration is a mandatory operation. In either event, calibration or no calibration, the system will expect appropriate commands to be entered via the DAS panel and it will manage its calibration request accordingly.

4.1.4 Safety Interlocks - If at any time during the automatic operation of the yaw alignment system and the shearer traverse, human intervention or power failure occurs to cause the automatic mode to default to remote or manual, the yaw alignment profile must be recalibrated prior to commanding the physical movement of any roof support. This is done as a safety precaution to prevent the possibility of any damage being done to the system by the inability of the yaw control memory to know if a critical element of the face conveyor system has been manually moved from the position it was last known to occupy. This default condition will be made known to the operator by the illumination of the "calibration" indicator on the MCS. The operator may then decide, on the basis of recent machine history, to calibrate the system or not to calibrate the system. Either decision may be implemented by issuing appropriate instructions to the system via the DAS input keyboard.

In the event that recalibration is required the shearer will traverse the face, read the angle cart data, recalculate position commands, issue the appropriate face conveyor and roof support com-

mands and resume normal automatic operation.

In the event that recalibration is not required by the operator, the system will assume that the last angle cart data set is still accurate and available to it in memory. It will extinguish the "calibration" light and resume automatic operation from its current location.

Because of the overlap in the start of the shear traverse with the start of the roof support pullup sequence it is concievable that a malfunction, environmental or otherwise, in the roof support sequence can cause a condition where a roof support is in motion in the vicinity of a moving shearer. A lockout is included in the system to guarantee that the shearer haulage motor speed is reduced to zero if any interruption in normal roof support activity occurs.

4.2 Yaw Alignment System Instrumentation Requirements - In the operation of the yaw alignment system two classes of information are required by the micro processor in order to properly operate the system. They are:

1) Sensor information needed from the roof supports for shearer control in the event of potentially catastrophic environmental interactions.
2) position and state Data for yaw alignment control feedback.

The following system control information (Item 1) is needed for proper instrumentation:

1) Roof support advance complete
2) Breakline forward
3) Calibration request

The roof support advance complete is required because we wish to assure that the shearer never traverses near a moving roof support. This, of course is to minimize potential problems of mechanical in-

terference. The breakline forward condition is a potentically catastrophic environmental interaction that can cause the shearer to crash into a roof support canopy. The last of the Item (1) type instrumentation imputs to the microprocessor yaw alignnment system, is the calibration input request. Whenever the shearer yaw alignment system is interrupted in its normal course of maintaining face conveyor and roof support alignment a calibration request signal is sent to the ECM and a mode change indicator is illuminated on the front panel.

The position and state data (Item 2) needed for yaw alignment is required to tell the alignment system that hydraulic pressure exists, the roof support load exists, the rams are properly positioned and the canopy is properly positioned.

4.2.1 Fault Instrumentation - Certain types of faults that must be monitored in the roof support system deserve special comment. A condition known as breakline forward can occur and can cause a roof support to misposition in such a way as to become an obstacle in the path of the on-coming shearer. This condition arises as a result of inhomogenus roof architecture that causes an unbalanced free load to be applied to the roof support sufficiently forward of its center of gravity to cause it to tip over into the path of the shearer. While not a frequent occurrence, breakline forward conditions can cause a relatively catastrophic problem with the shearer and must be instrumented in such a way as to cause an immediate "shrdon", i.e.: interrupt, condition when it occurs.

The detection of this problem is accomplished by allowing the microprocessor to perform an analysis of the vertical ram extension, roof support load and recent movement history. Sensors required to do the job are vertical ram encoder and hydraulic pressure sensor on the vertical ram.

Advance complete signals from the individual roof supports are needed in order for the yaw alignment system to properly sequence the roof support or face conveyor movements. A failure to receive

a roof support advance complete signal by the yaw alignment processor will cause the alignment sequence and the shearer travel to be interrupted until the malfunction is repaired or over-ridden by DAS control

A procedural assist is required in order for the yaw alignment system to know when to request a calibration signal. It will be assumed that whenever anyone removes his key from an end roof support that a face conveyor section or roof support has been moved. Any time that the MCS is put into the remote mode it will be assumed that a roof support or face conveyor section has been moved. Any time a power failure occurs the yaw alignment system will lose track of its operation at the time of the failure. For each of these conditions the calibration light will be illuminated to request operator intervention. In all cases of power failure recalibration is needed. In cases of mode change or key removal, the need for calibration becomes a matter of operator judgement.

Recalibration, if required, is caused to occur by entering the appropriate command through the DAS keyboard. The system will then take angle cart readings on its next complete traverse and utilize these readings to control face conveyor position and roof support pullup.

The remaining sensors used to operate the yaw alignment consists of horizontal RAM position encoder, hydraulic pressure sensor and limit switches on the Vertical Ram.

The horizontal ram encoder is used by the yaw alignment system to keep track of the positions of the face conveyor and roof support.

4.2.2 <u>System Configuration</u> - The yaw alignment system operates to keep the face conveyor at a specified level or straightness for maximum coal mining efficiency. This is accomplished by periodically measuring the angles between face conveyor sections with a differential resolver (angle cart) that rides on the shearer. The raw data

accumulated by the angle cart is then used to calculate displacement coordinate relative to a surveyed stake, in the mine, for each face conveyor section. This displacement profile is then algebraically combined with the requirements of the mining method (half or full face sump) to produce displacement distance values for each horizantal ram in the roof support system.

The horizantal ram data is transmitted to each roof support, via the communication link.

Activation commands are then sent to the roof supports that are a funciton of mining method, previous recent system history, position of the shearer and whether or not a clean up pass is requested by the operator. These actuation commands will cause the face conveyor sections to be positioned for the next traverse down the face. The hydraulic pressure sensor is used to transmit the condition (if malfunctioning) to the hydraulics indicator on the MCS. The vertical ram limit switches are used to tell the system that the vertical ram has reached its limit. If the roof support pressure sensor does not indicate roof pressure then the system will assume a void in the roof.

After the face conveyor is properly positioned for a pass down the face similar positioning commands are developed for the roof supports and certain of them are sequenced forward according to the roof support algorithm used. The data base used to develop the roof support commands consists of, mining method algorithm, shearer position and previous recent system history. An interface dialog carried on with the roof supports and the ECM provides operational and safety interlocks in the system so as to allow shearer travel and roof support activity at opposite ends of the face conveyor to proceed simultaneously. No shearer travel is allowed during face conveyor placement.

The yaw alignment control system operates under the system mon-

itor "Roofup" by the exection of a number of independent subroutines whose call-returns and pass conventions are supervised by the system monitor. These subroutines are:

Ancart	This subroutine reads angle cart data and processes it into useable form.
Math	This subroutine calculates the yaw profile corrections from angle cart data.
Face	This subroutine uses the profile corrections, mining method algorithm and shear position to operate the face conveyor placement algorithm.
Manag	This subroutine places the roof supports up against the face conveyor at the proper time.

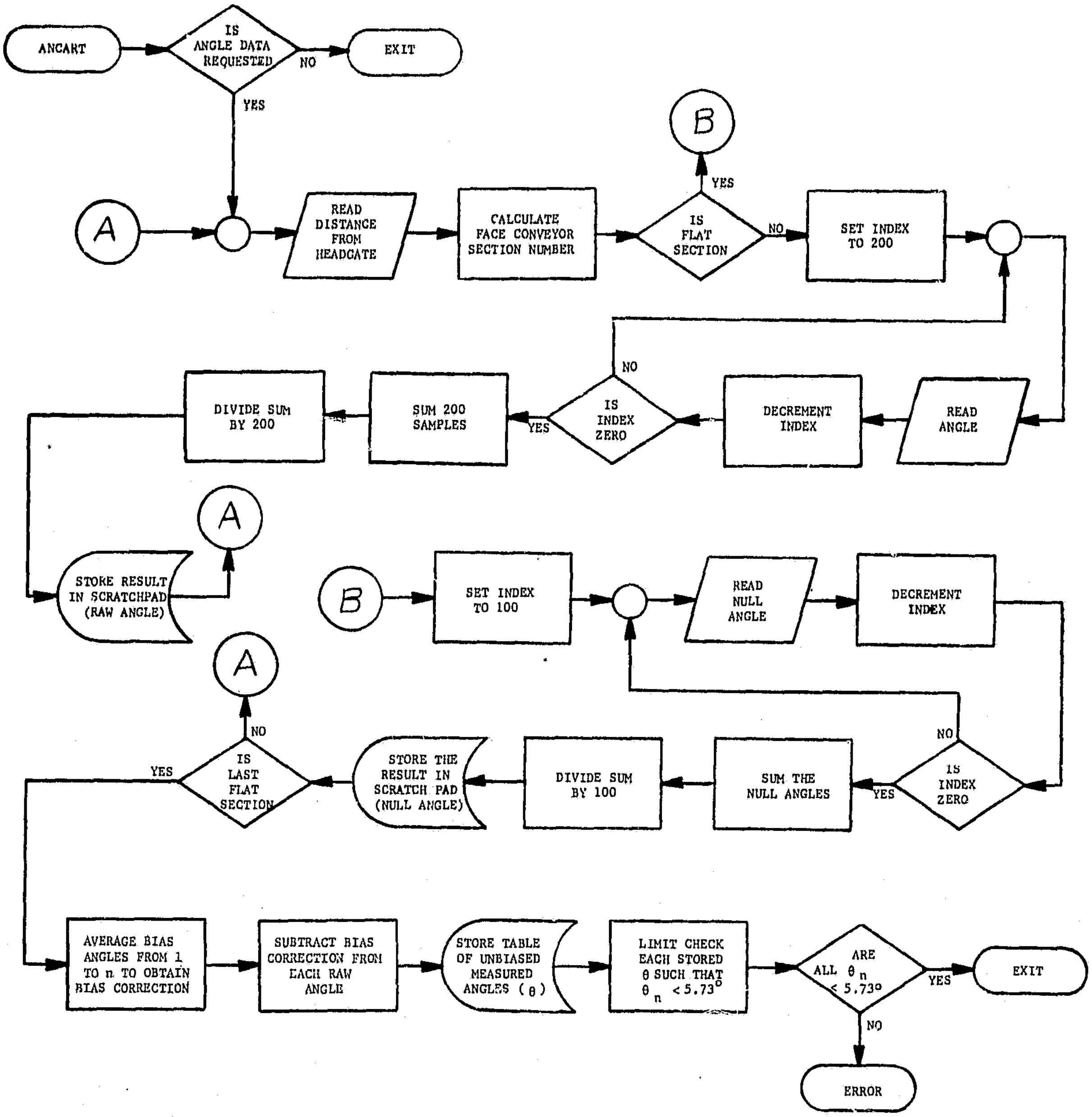
4.2.2.1 Ancart, Figure 4-2 - The Ancart Subroutine processes the digitized resolver outputs of the angle cart in real time as the shear traverses the face.

The raw angle data is processed according to the following relationship.

$$\theta_{Rn} = \frac{1}{200} \sum_{i=1}^{i=200}$$

Each raw angle θ_{Rn} is calculated and then stored according to the face conveyor section associated with it. The angles θ_{Rn} so calculated contain a bias error that is a function of bias in the angle cart. When the angle cart is used to measure the flat portion of the face conveyor (no angle) the digitized value should be zero. This bias error is obtained by measuring the flat section and performing the following calculation.

$$\alpha_n = \frac{1}{100} \sum_{i=1}^{i=100} \alpha_i$$



$$R_n = \frac{1}{200}\sum_{i=1}^{i=200} \theta_i \qquad \text{(RAW ANGLE)}$$

$$\alpha_b = \frac{1}{N}\sum_{n=1}^{n=N} \frac{1}{100}\sum_{i=1}^{i=100} (\alpha_n)_i \qquad \text{(BIAS)}$$

$$\theta_n = (\theta_{Rn} - \alpha_b) \qquad \text{(UNBIASED ANGLE)}$$

ARE ALL $\theta_n < 5.73^\circ$

Figure 4-2. Yaw Alignment Software Routine (ANCART)

Each α_n is limit checked to verify that it is sufficiently small so that the small angle approximation applies and then it is stored in its scratch pad location. At the end of the shearer pass, when a value α_n has been stored for each face conveyor section these values are summed and divided by N to obtain a value for α_b that can be used to correct resolver outputs.

$$\alpha_b = \frac{1}{N} \sum_{n=1}^{n=N} \alpha_n$$

4.2.2.2 Math, Figure 4-3 - The math algorithm takes the processed angle cart data and develops a function ΔY_{PN} which is the horizontal ram displacement required under conditions of face conveyor straightening. The calculation proceeds as follows:

Figure 4-3, page 1 of 3

Form A Table of "γ" angles as follows:

$$\gamma_2 = \theta_2 \qquad \theta_n = \text{Measured Angle}$$

$$\gamma_n = (\theta_n + \gamma_{n-1}) = \sum_{j=2}^{j=n} \qquad \gamma_n = \text{Computed Angle}$$

then calculate the yaw displacement profile as so:

Y_o = Initial Condition Parameter

$$Y_N - Y_o + L \sum_{i=1}^{i=N} \delta i$$

Y_N = Displacement of N th Section

L = Length of Section

This equation is solved for the initial conditions that $\theta_1 = 0$ and Y_o and Y_N are known initial condition parameters. By solving for θ_1 it is possible to obtain the angle with the horizontal of the

first section of conveyor; this could not be measured by the angle cart. After storing θ_1 and putting it into the equation above a table of Y_n values may be determined. These are the displacement values of individual face conveyor sections.

Figure 4-3, page 2 of 3.

This part of the subroutine analyses the table of Y_n values to determine whether or not sufficient error exists to warrant a straightening exercise. The calculation proceeds in the following way:

$$(Y_{Max} - Y_{Min}) = \lambda$$

$$\text{Straighten if } \lambda \geq B$$

$$\text{Don't Straighten if } \lambda < B$$

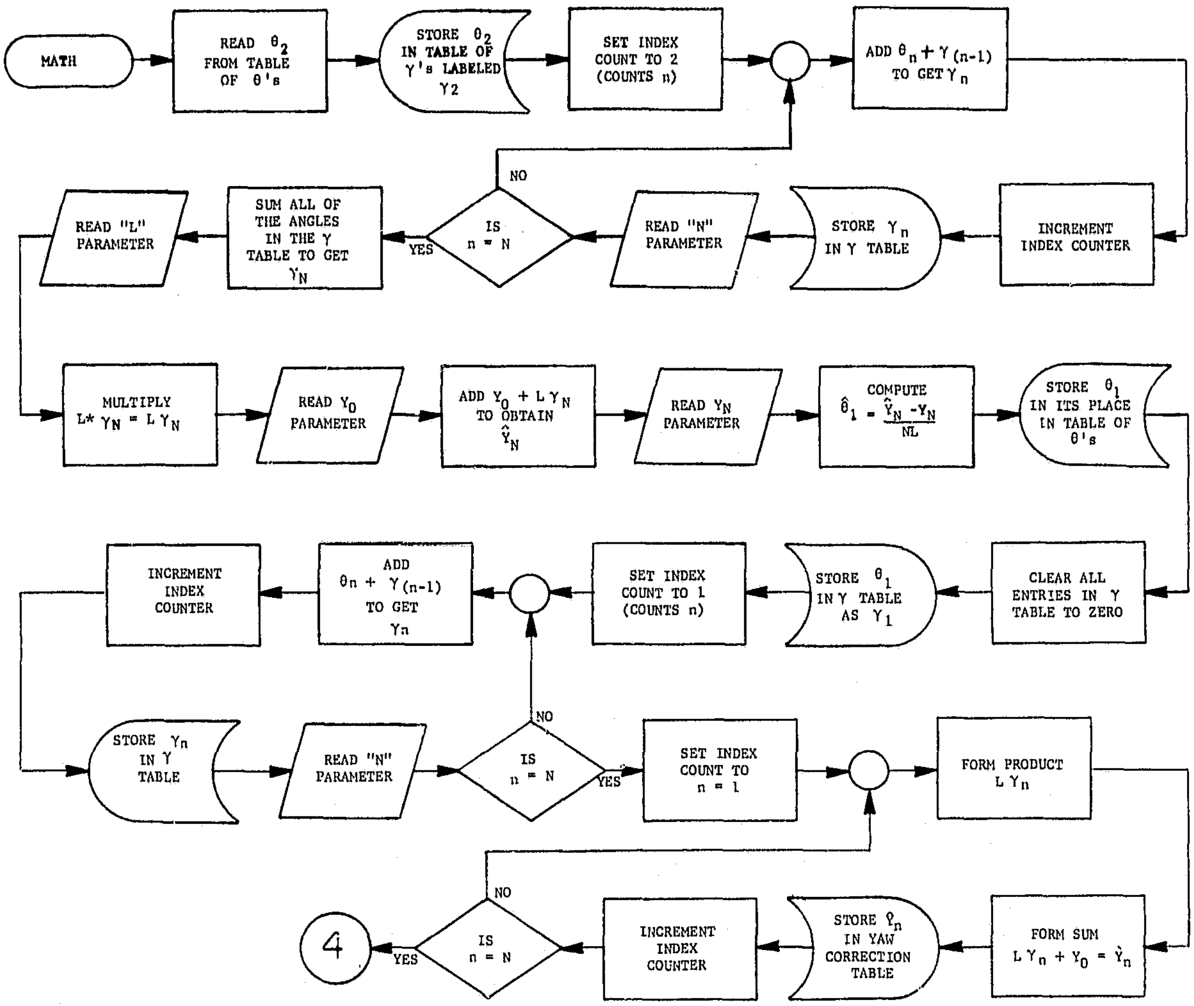
Where B is the criteria parameter introduced into the system through the digit switch on the MCS.

Figure 4-3, page 3 of 3.

This subroutine interates N solutions to the following relationship to produce a table of ΔY_{PN} values:

$$\Delta Y_{PN} = \frac{Y_A - K}{Y_A} \left\{ Y_A + \lambda \left(Y_{Min} - .5 \left(Y_n = Y_{n-1} \right) \right) \right\} + K$$

Y_{PN} = Horizontal Ram Strightness Value
K = Amount of Straightness Required
Y_A = Uncorrected Maximum Ram value
λ = 1 for straighten; = 0 for don't straighten
Conditions: $1 \leq n \leq N$



$$\hat{Y}_n = Y_0 + L \sum_{i=2}^{i=N} Y_i$$

$$Y_i = \sum_{j=2}^{j=i} \theta_j \equiv \gamma_n = (\gamma_{n-1} + \theta_n)$$

Figure 4-3. Yaw Alignment Software Routine (MATH) (Page 1 of 3)

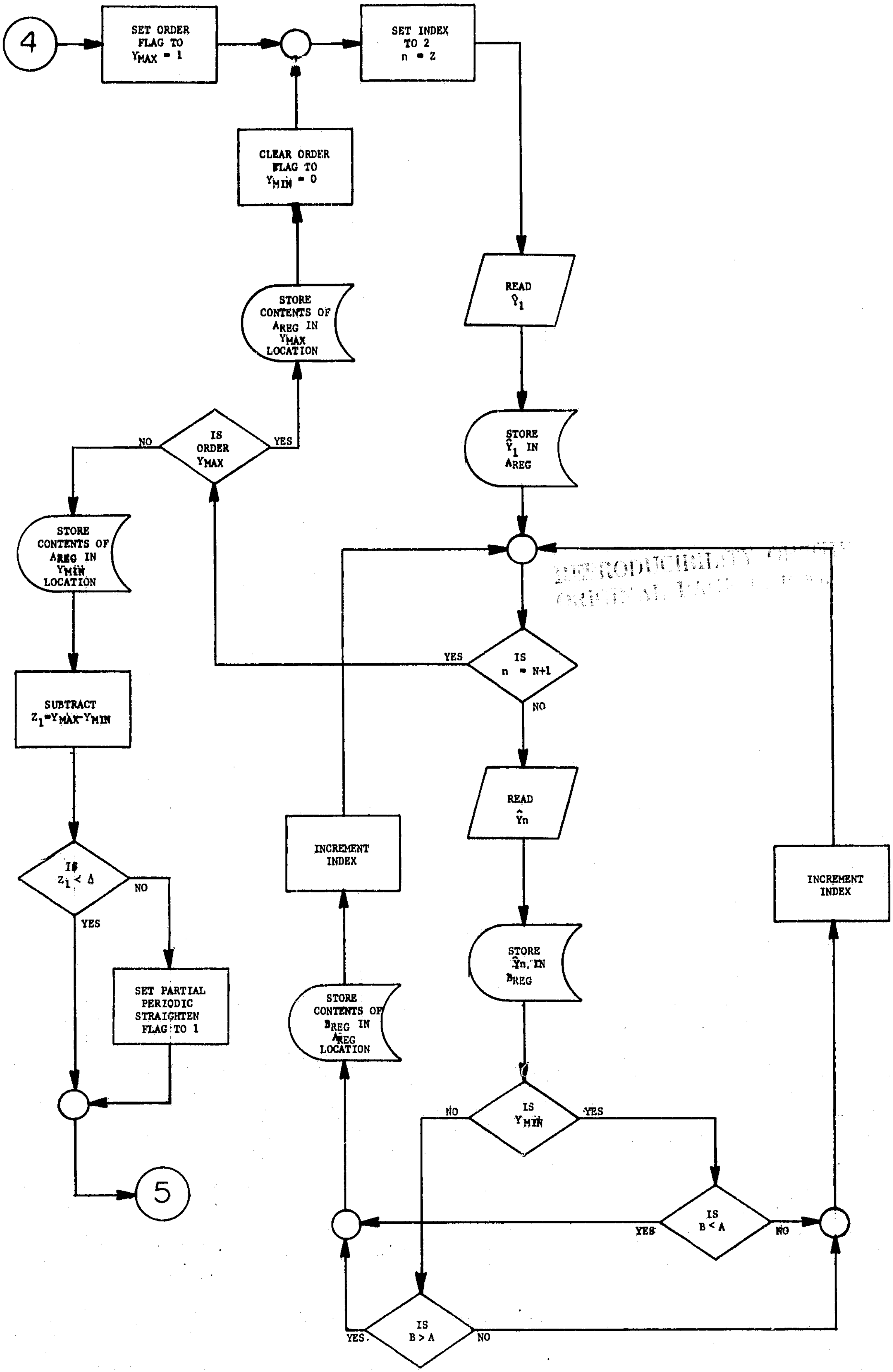
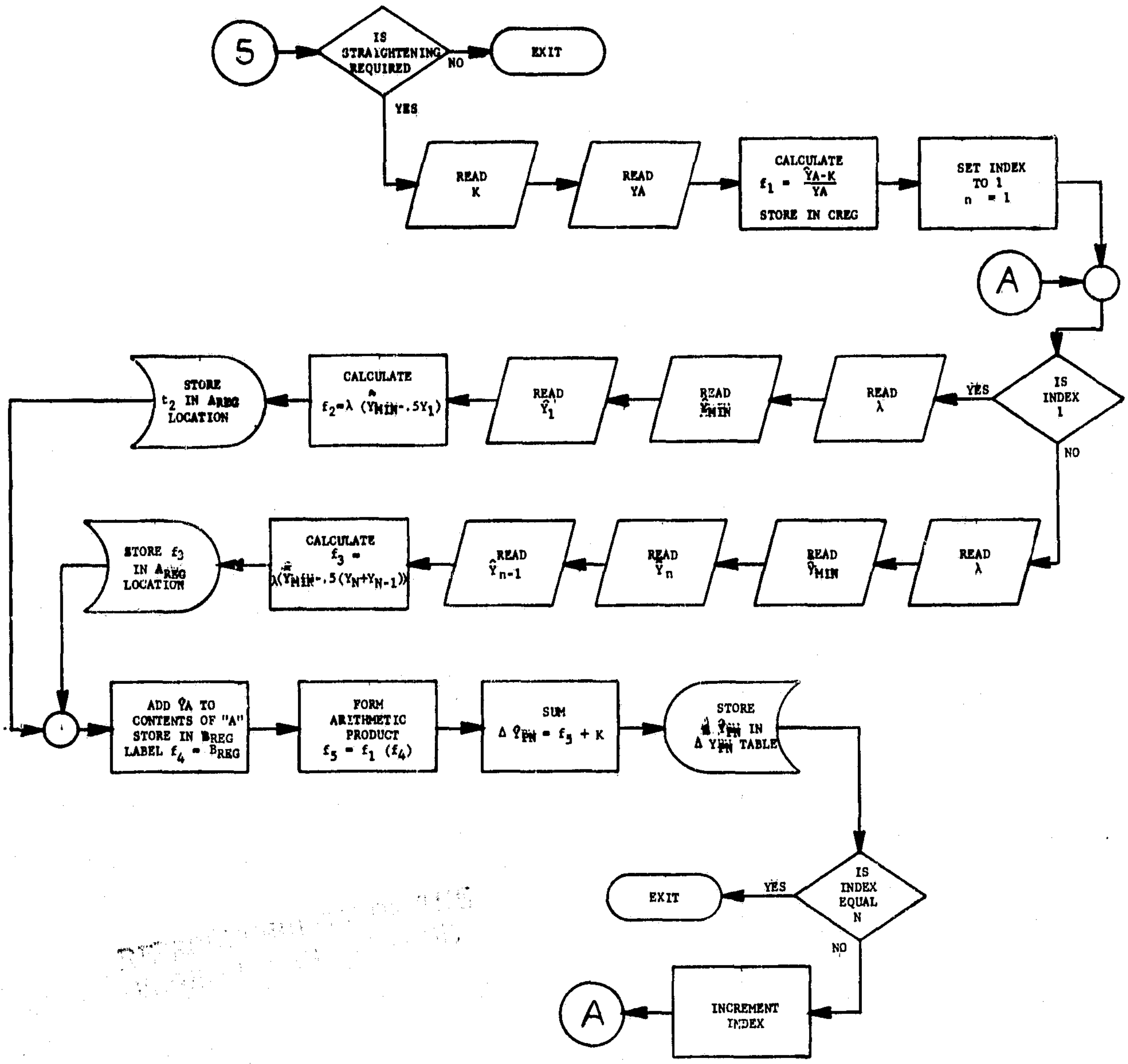


Figure 4-3. Yaw Alignment Software Routine Z1 = YMAX - YMIN STRAIGHTEN FLAG = 1 IF ≥ Δ
(MATH) (Page 2 of 3)



$f_1 = \frac{\hat{Y}A-K}{\hat{Y}A}$

$f_2 = \lambda(\hat{Y}_{MIN} - .5\hat{Y}_1)$

$f_3 = \lambda\,(\hat{Y}_{MIN} - .5\,(\hat{Y}_N + \hat{Y}_{n-1}))$

$f_4 = \hat{Y}A + f_3$

$f_5 = f_1\,(f_4)$

$\Delta\,Y_{PN} = f_5 + K$

Figure 4-3. Yaw Alignment Software Routine (MATH) (Page 3 of 3)

4.2.2.3 Face, Figure 4-4 - The face subroutine sends horizontal ram displacement data to the roof supports modified according to roof support location relative to the headgate to implement the sumping procedure used.

When the shearer is at the headgate:

ΔY_{PN} on the tailgate side of the snake is equal to 1

ΔY_{PN} on the headgate side of the snake is equal to 0

ΔY_{PN} on the snake is maximum on tailgate end and minimum for headgate end from snake table

When the shearer is at the tailgate

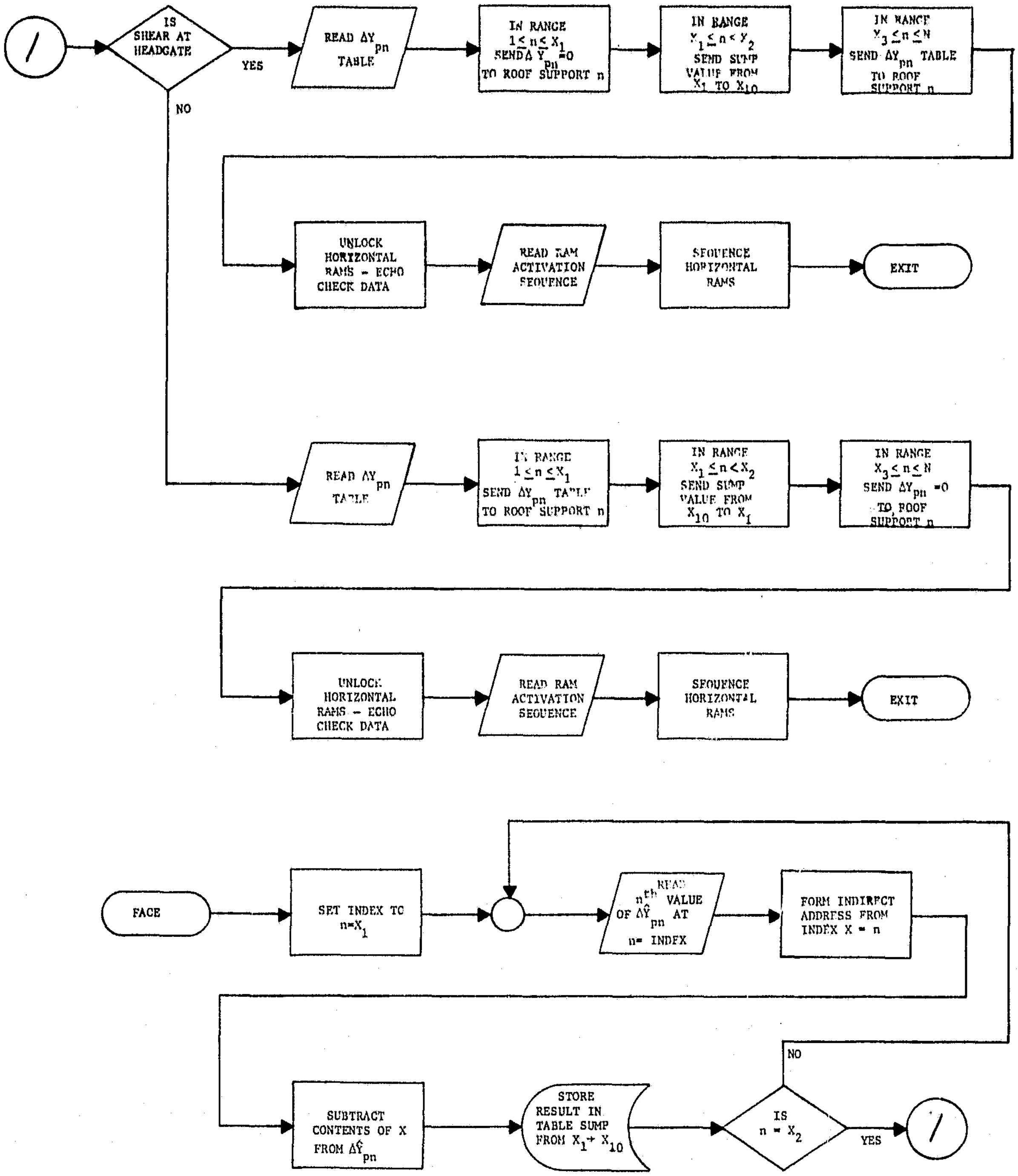
ΔY_{PN} on the tailgate side of the snake is equal to 0

ΔY_{PN} on the headgate side of the snake is equal to 1

ΔY_{PN} on the snake is maximum on headgate end and minimum for tailgate end from snake table.

After delivering the data for horizontal ram motion to the roof supports, the Face program sequences the horizontal rams to the extension distance ΔY_{PN} programmed into them and awaits the "move complete" signal from the most distant roof support, i.e.: the lowest ordered one if shear at tailgate; the highest ordered one if shear is at headgate.

4.2.2.4 Manag, Figure 4-5 - The "Manag" program examines the extension of the horizontal rams on those roof supports in the snake region and the position of the shearer and calculates which roof supports must be moved forward to the face conveyor. The algorithm is:



ROOF SUPPORT ADDRESS CONVENTION

HEADGATE SIDE OF SNAKE

$1 \leq n \leq X_1$

SNAKE SECTION

$X_1 \leq n \leq X_2$

$(X_2 - X_1) = 10$

TAILGATE SIDE OF SNAKE

$X_2 \leq n \leq N$

N = TOTAL NUMBER OF ROOF SUPPORTS

Figure 4-4. Yaw Alignment Software Routine (FACE)

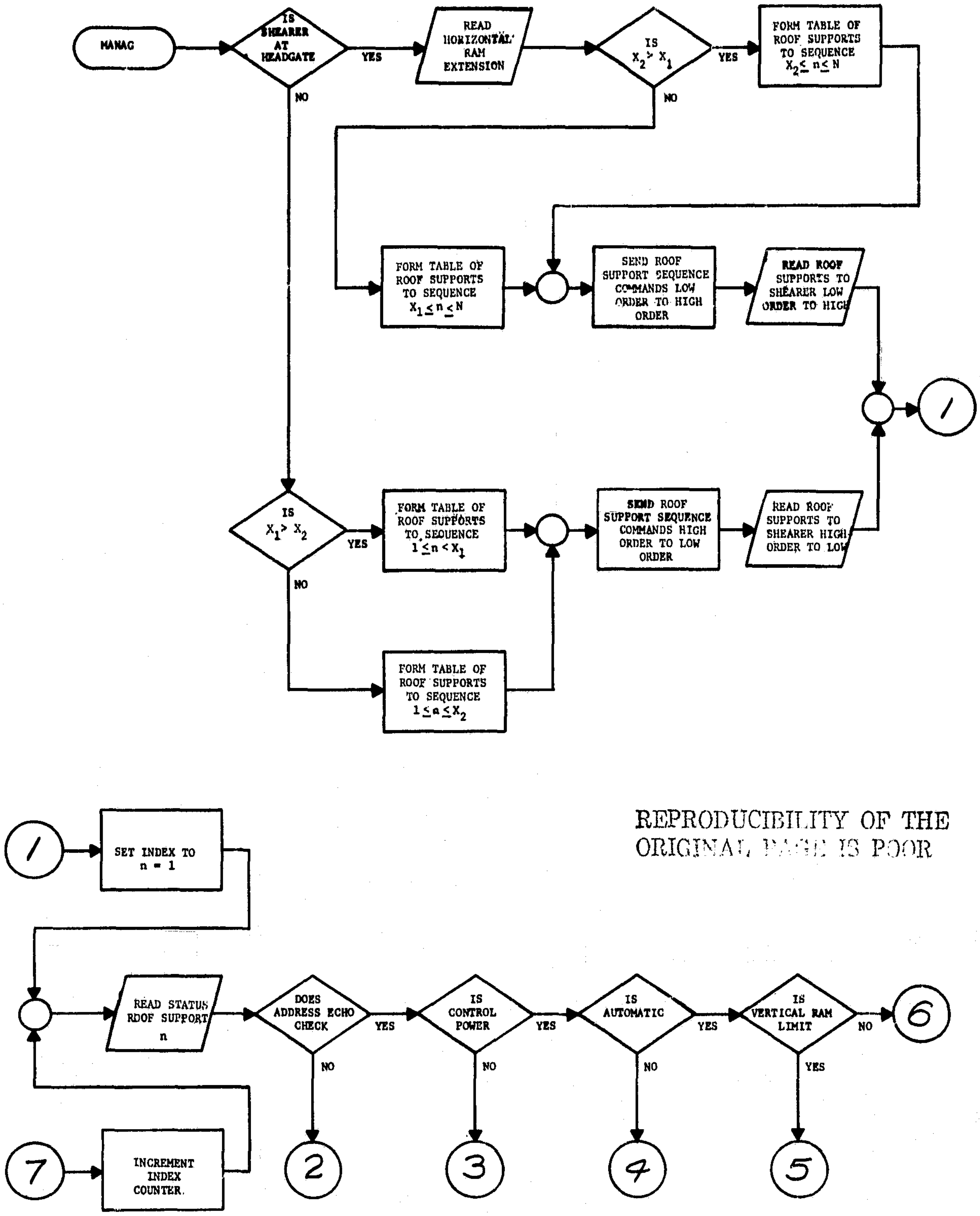


Figure 4-5. Yaw Alignment Software Routine (MANAG) (Page 1 of 2)

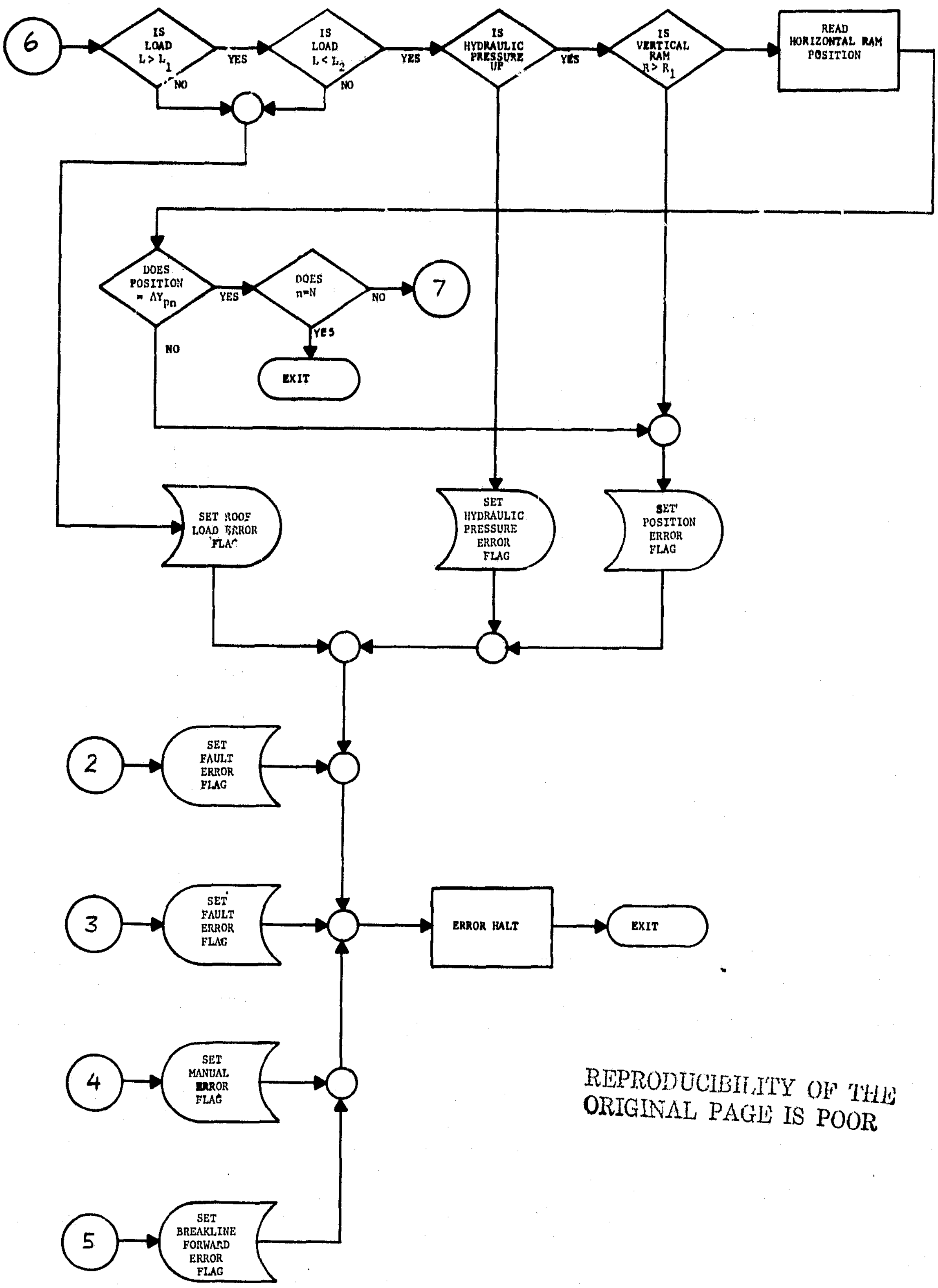


Figure 4-5. Yaw Alignment Software Routine (MANAG) (Page 2 of 2)

If at Headgate:

$X_2 > X_1$ Sequence $X_2 \leq n \leq N$

$X_1 \geq X_2$ Sequence $X_1 \leq n \leq N$

If at Tailgate

$X_1 > X_2$ Sequence $1 \leq n \leq X_1$

$X_2 \geq X_1$ Sequence $1 \leq n \leq X_2$

Where the X displacements are defined:

1	X_1	X_2	N
Headgate	snake		Tailgate

Since the direction of the roof support sequence is a function of which end the shear is at when the sequence starts the Manag program must sequence low order to high when shear is at headgate and high order to low when shear is at tailgate.

In addition to moving the roof supports the Manag program sequentially polls the roof supports to read performance and malfunction data for use by the master monitor roofup and for display at the MCS.

4.2.2.5 Roofup, Figure 4-6 - The master monitor, Roofup, in addition to supervising subroutine linkages also interconnects the subroutines in such a way as to implement the mining method selected either with or without a cleanup pass. The roofup program will also intervene to force a calibration pass of the shearer when requested by the operator at the DAS keyboard. No supervision is exercised by Roofup over the remote or manual modes of operation. The manual mode is independent of the software system entirely; the remote mode is a system of discrete microcontrol accessed by the MCS operator.

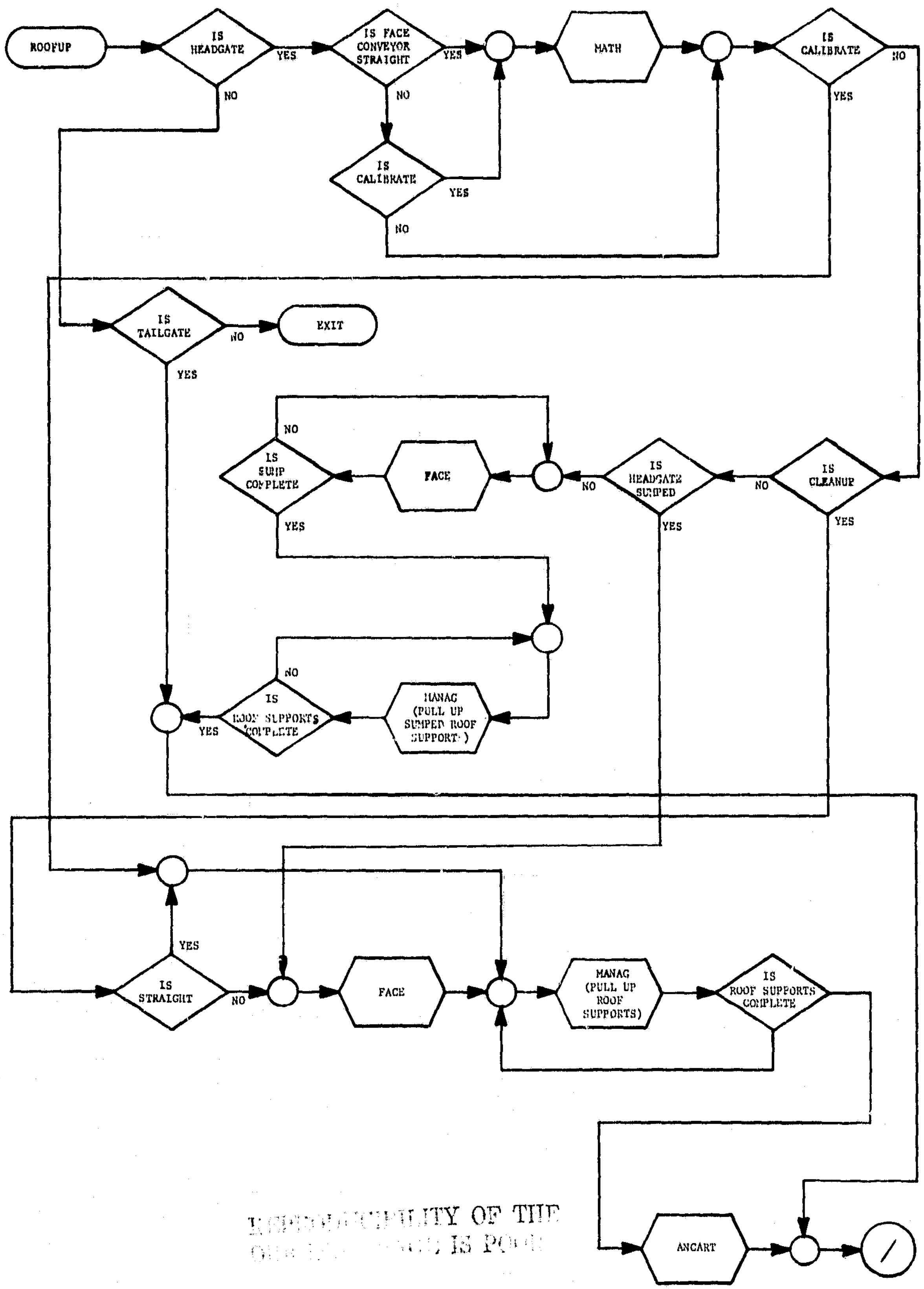


Figure 4-6. Yaw Alignment Software Routine (ROOFUP) (Page 1 of 2)

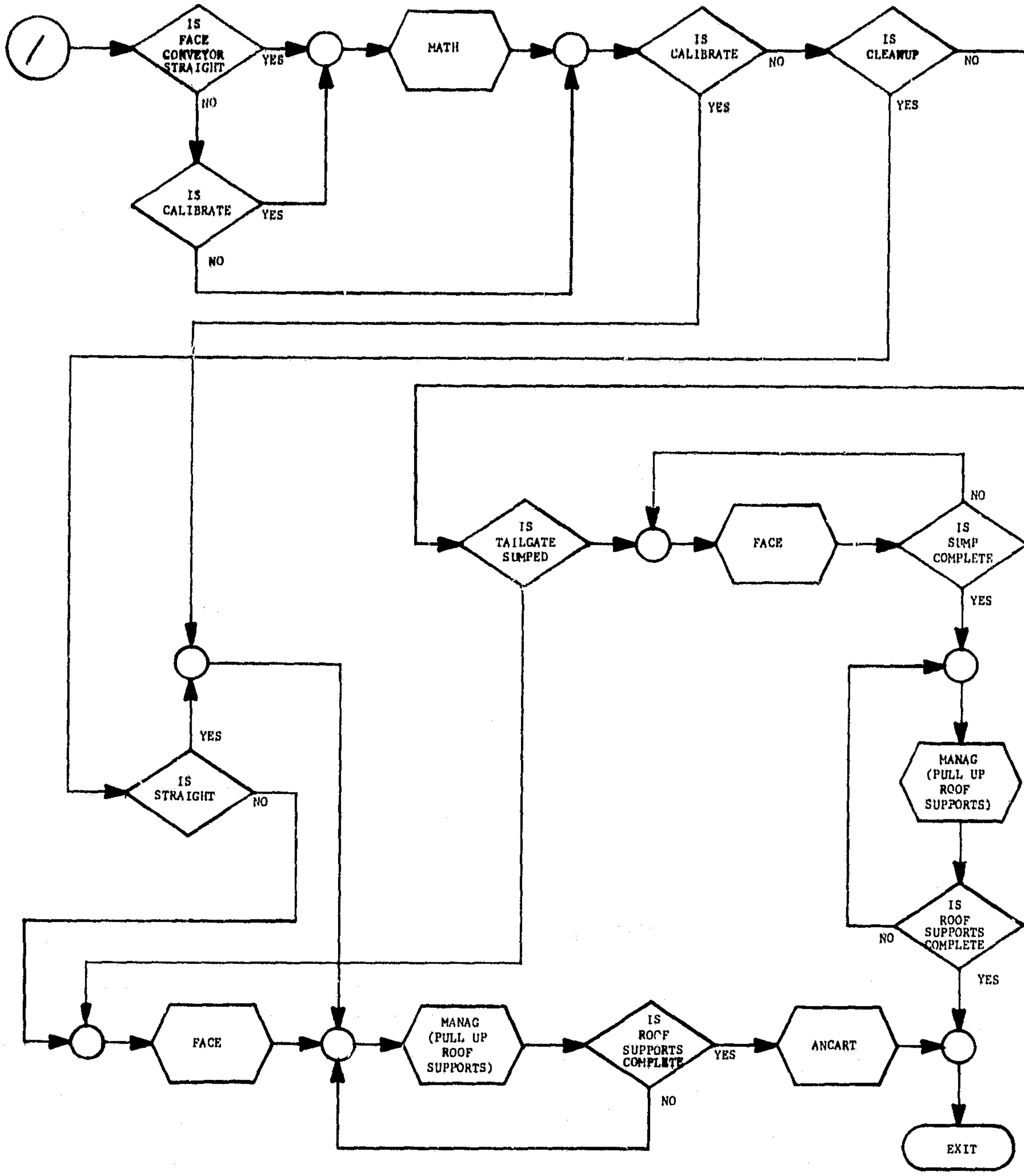


Figure 4-6. Yaw Alignment Software Routine (ROOFUP) (Page 2 of 2)

4.3 Electronic Design of The Longwall Yaw Alignment System

The Automated Longwall Guidance and Control System consists of three major electronics hardware blocks, the Electronic Control Module (ECM) with its associated power supply, the Yaw Alignment System (YAS), and the Master Control Station (MCS) with its associated power supply. The ECM Electronics has been largely considered in the VCS report Phase 2. The YAS electronics consists of electronic packages mounted on each of the roof supports to implement their proper advance command and control, and an angle cart device-integrated with the shearer for measuring conveyor alignment from which roof support advance commands are generated. The MCS, located on the stage loader in the headgate area, is the central control and monitoring station for the Automated Longwall Guidance and control System. Virtually all system functions can be monitored and controlled from this location.

The shearer mounted ECM is the electronic heart of the Automated Longwall Guidance and Control System and contains most of the monitoring, command and control, and processing electronics. As such the ECM contains the electronics for the three major control loops needed for automated longwall operations which are the Yaw Alignment System (YAS), the Roll Control System (RCS), and the Vertical Control System (VCS). The present portion of the study is concerned primarily with the design of YAS and hence the primary emphasis will be on this design. Consideration is given to the VCS and RCS electronics only to the extent necessary to clarify hardware-software partitioning amongst the subsystems.

4.3.1 Preliminary Electronic Considerations - Besides the VCS, as described in a previous report and the Roll Control described in a following section of this report the emphasis for this portion of this longwall automation report is on the yaw alignment system. The electronics circuits, subsystems, and algorithm described are the result of a preliminary design that is required to automatically advance the conveyor and roof supports. This advance is such that

C-2

the conveyor "straightness" remains within acceptable limits and perpendicular to both headgate and tailgate.

4.3.1.1 Top Level System Trade-Offs - Before the preliminary design of the Longwall automation could proceed several top level system trade studies were performed. These are described below:

4.3.1.1.1 Digital vs Analog Implementation - The first trade off to be considered is whether the system implementation should be analog or digital. One of the primary considerations in determining system implementation is the electromagnetic (E&M) environment in which the equipment will be required to operate. Due to the large electrical motors on the shearer proper (i.e., drum cutter motors, shearer haulage motor), and the large electrical motors that are required to drive the face conveyor, stage loader, and panel conveyor, the potential for E&M interference is high. Substantial design effort would be required to worst case noise thresholds critical to an analog implementation in this environment. Digital chips available economically are already designed with near optimum noise immunity. Therefore, from an E&M viewpoint a digital system implementation, including digital sensor encoding wherever possible, would minimize the effects of E&M interference and is much preferred over its analog counterpart.

Given the complexity of the required longwall control, data processing, and status monitoring algorithms it would be difficult to specify an analog system implementation even if the algorithms were to remain constant and not require change. However due to the variations in mining conditions and physical coal parameters the longwall algorithms will require periodic change and modification. By the use of digital techniques many control and operational parameters may be readily modified to meet changing environmental conditions by simply changing the program and reading the new program into the memory. This is considerably simpler than going to the mine environment during a maintenance schedule and modifying or re-

placing analog hardware. By designing the digital hardware properly, the system configuration as well as it's operating parameters become substantially software dependent and relatively hardware independent. A considerable level of sophistication has been achieved in the compiling of software and in devising useful special purpose software routines. The use of these techniques simplifies the design task to a considerable extent. In addition considerable engineering effort has been expended in the last fifteen years by industry to provide the systems engineer with a variety of thoughtfully designed digital building blocks to further simplify system design.

Due to the above outlined considerations a digital rather than analog design approach has been adopted for the automated longwall system.

4.3.1.1.2 Software vs Hardware Trade Offs - When the digital hardware is initially designed many of the tasks that must be performed may be performed either by simple programs operating in complex hardware configurations or by complex programs operating in simple hardware configurations. In may cases the systems designer has degrees of freedom in assessing these trade offs. The basic philosophy used in the design of the ECM, MCS, and YAS is to strive for simple hardware configurations.

4.3.1.1.3 Multiplexing vs Direct Lines - Because of the complexities associated with multiplexing the sensor information from the sensors on the shearer to the ECM box, direct wires were chosen as the transfer mechanism. These wire lines include the YAW correction wires from the angle cart. This trade study was assessed in the previous report dealing with the Vertical Control System.

The transfer of data between the ECM, YAS and MCS is not best handled with wire lines. While a direct wire would be faster in transfering data, the cost and complexity associated with this technique is prohibitive. To wire an interface consisting of address

lines, data lines and handshake control lines to each of 120 or so roof supports without a multiplexed bus structure is not considered practical.

4.3.1.1.4 Minicomputer vs Microprocessor Trade Offs - After the analog/digital/software tradeoffs were evaluated and basic systems design decisions were established, the implementation with microprocessor vs minicomputer technology was studied.

The longwall system requires approximately 400 input/output (I/O) lines and also substantial computational power in the computer system selected. The minicomputer is superior to the microprocessor in computational power but has limited I/O capability. The microprocessor, on the other hand, is an ideal control device with powerful I/O structures but with limited computational ability. However an ample supply of building blocks, microprocessor compatible, which can enhance the computational ability for control applications are available. Typical of these building blocks are a number of arithmetic logic units (ALU's), microprocessor compatible, that have been developed for calculator applications. By interfacing one or more of these devices in a distributed processing network through the microprocessor I/O system, a very nearly ideal systems solution may be obtained. This solution provided a very powerful set of I/O command and control instructions together with a very powerful computational ability. This proved to be a contributing reason for the selection of microprocessor technology for this application.

A second, and important, advantage of the microprocessor is the ease of interfacing it to the sensors, encoders, hydraulic actuators, motor controllers and other auxiliary devices. A large number of microprocessor compatible chips are available to simplify this interfacing problem. Minicomputers, on the other hand, typically have a fairly complex I/O interface, primarily suited to data exchanges with EDP terminals, line printers, tape stations and disc files. Controllers may be designed to service large numbers of I/O

lines, however to do so would force a more complex and less maintainable design. The microprocessor approach utilizes a fairly standard chip set in a simple easily maintained technology.

A third and important reason for the selection of microprocessor technology is that of power limits which are intrinsically safe and do not require an explosion proof box. Typical of the TTL logic used in a minicomputer is a J-K flip flop which uses up to 25 ma quiescent current. The same logic device implemented in the CMOS microprocessor utilizes approximately 1% of this power supply current thus enabling intrinsically safe power levels to be met.

A fourth and significant reason for the selection made is that of reliability. CMOS technology was primarily developed for reliability enhancement, a prime consideration when operating in the mine environment.

4.3.2 Operability - Operability, as a figure of merit, for the design of the longwall shearer consists basically of determining the answers to four questions:

1. At what rate does the system mine coal.
2. How long will it continuously mine coal before it experiences a repairable failure.
3. How long does it take to fix the repairable failure when it occurs.
4. How long do we operate with reduced or no coal production.

The design goal for coal mining rate is nominal operation at 30 ft/min with 50 foot per minute maximum traverse speed along the face with no appreciable degradation in performance. The mean time to failure and the mean time to repair are reliability and maintainability design goals to be established in the design phase of the program. It is clear that a mean time to failure figure in the hun-

dreds of hours and a mean time to repair in the tens of hours are practical and readily obtainable with current technology.

4.3.2.1 Reliability - Reliability of the system is expressible in terms of mean time between failures (MTBF). The calculation of this number is performed by carefully summing weighted reliability indicies for each of the separate components in the system. These weighted indicies, when examined, are found to be a statistical composite involving component quality, power dissipation, operating temperature and voltage/current stress levels. Such a calculation cannot be performed until parts specification and detail design and analysis are complete.

The 30 foot/minute nominal traverse velocity for the shearer is established largely from considerations of improving the present coal mining efficiency by a factor of three to five. This means that the system must reflect MTBF numbers and mean time to repair (MTTR) numbers that do not detract from the operating performance targets.

During the design and development stage it is important to organize the design effort to assure industrial grade parts quality, low parts stress levels, power de-rating of components and a thermal design free of hot spots thus enhancing system reliability.

4.3.2.2 Maintainability - All physical systems are subject to some failure, sometime, under some set of conditions. When such a failure does occur with the longwall shearer it is important to be able to effect repairs quickly, easily and in the mine environment where the failure takes place. This dictates that all functional components, i.e., box level, be replaceable easily and in the mine environment. This also dictates that the design be performed so that consequential failures are eliminated. If a single point failure occurs, the systems design must preclude the possibility of a fire cracker like string of consequential failures from being caused to occur.

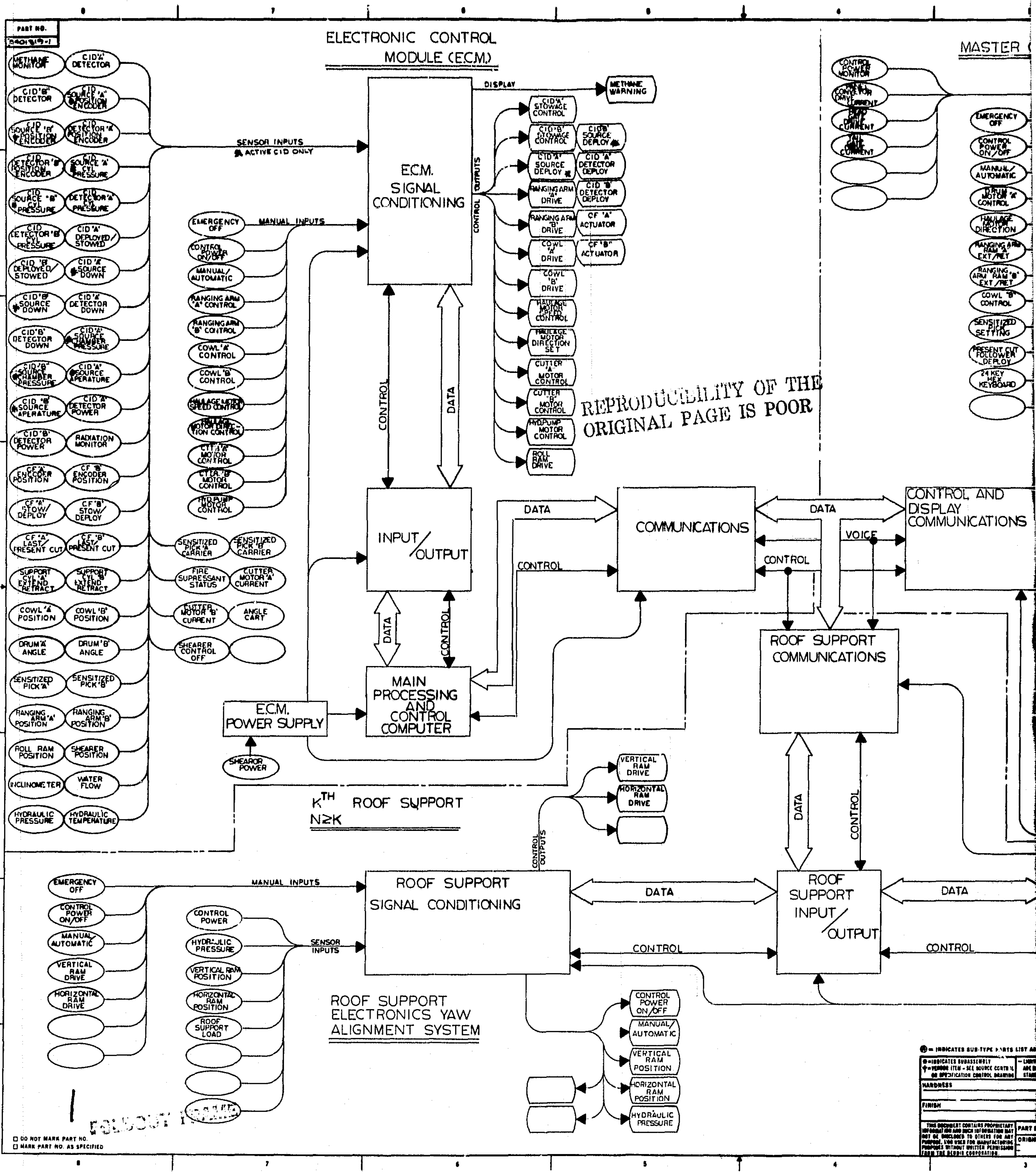
Major subsystems in permissible boxes must be easily diagnosed (by the DAS controller) and replaced quickly in the mine environment. The explosion proof boxes must be replaceable, in situ, in a reasonable amount of time. (i.e., within one maintenance shift)

Those subsystems that can be shown to have a very long MTBF, i.e.: cable harness, need not meet the simply and easily replaceable criterion.

4.3.3 System Electronics - Because the YAW alignment portion of the Longwall automation requires the use of the electronics in the ECM (on board the shearer), the MCS located on the stageloader, and the YAS located on each of the roof supports, the YAW alignment preliminary design must include these subsystems. Also included with the YAW alignment electronics is the electronics required for implementing portions of the other Longwall automation functions.

Figure 4-7 is a block diagram showing how the longwall automation assemblies interface. The sensor and control inputs into the various assemblies are listed as are their control outputs. The data and control paths are also indicated for continuity in information flow throughout the longwall automation electronics. This diagram segregates the assemblies into the three major electronic hardware blocks consisting of the Electronic Control Module (ECM), the Master Control Station (MCS), and the electronics mounted on the roof supports which in conjunction with the shearer mounted angle cart from the YAW Alignment System (YAS). One roof support electronic subassembly is shown which is typical of the roof support mounted electronics used along the longwall face. The communications subsystems are not separately defined and have been integrated within their respective subassemblies.

Figure 4-7 indicates all of the inputs to the different subsystems required for Longwall automation, as well as the control requirements to implementation of these operations. The systems


ELECTRONIC CONTROL MODULE (E.C.M.)
E.C.M. SIGNAL CONDITIONING
SENSOR INPUTS
MANUAL INPUTS
DISPLAY
METHANE WARNING
CONTROL OUTPUTS
CONTROL
DATA
INPUT/OUTPUT
MAIN PROCESSING AND CONTROL COMPUTER
E.C.M. POWER SUPPLY
SHEAROR POWER
COMMUNICATIONS
CONTROL AND DISPLAY COMMUNICATIONS
VOICE
ROOF SUPPORT COMMUNICATIONS
MASTER
K^{TH} ROOF SUPPORT
N≥K
ROOF SUPPORT SIGNAL CONDITIONING
ROOF SUPPORT INPUT/OUTPUT
ROOF SUPPORT ELECTRONICS YAW ALIGNMENT SYSTEM
METHANE MONITOR
CID 'A' DETECTOR
CID 'B' DETECTOR
EMERGENCY OFF
CONTROL POWER ON/OFF
MANUAL/AUTOMATIC
RANGING ARM 'A' CONTROL
RANGING ARM 'B' CONTROL
COWL 'A' CONTROL
COWL 'B' CONTROL
RADIATION MONITOR
COWL 'A' POSITION
COWL 'B' POSITION
DRUM 'A' ANGLE
DRUM 'B' ANGLE
SENSITIZED PICK 'A'
SENSITIZED PICK 'B'
ROLL RAM POSITION
SHEARER POSITION
INCLINOMETER
WATER FLOW
HYDRAULIC PRESSURE
HYDRAULIC TEMPERATURE
FIRE SUPRESSANT STATUS
ANGLE CART
SHEARER CONTROL OFF
VERTICAL RAM DRIVE
HORIZONTAL RAM DRIVE
VERTICAL RAM POSITION
HORIZONTAL RAM POSITION
ROOF SUPPORT LOAD
CONTROL POWER
ROLL RAM DRIVE
24 KEY HEX KEYBOARD

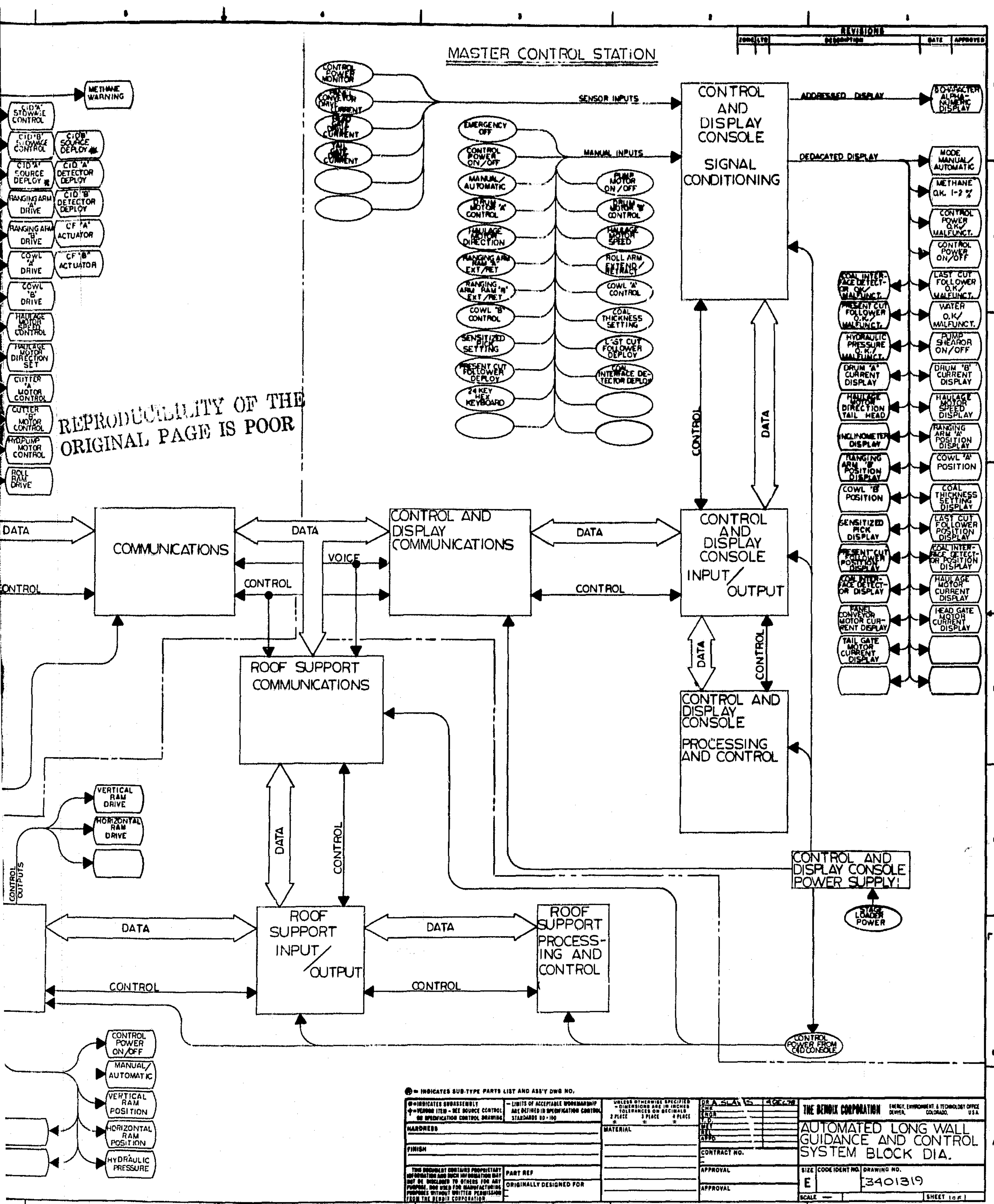

MASTER CONTROL STATION
CONTROL AND DISPLAY CONSOLE SIGNAL CONDITIONING
SENSOR INPUTS
MANUAL INPUTS
ADDRESSED DISPLAY
DEDICATED DISPLAY
CONTROL POWER MONITOR
EMERGENCY OFF
CONTROL POWER ON/OFF
MANUAL/AUTOMATIC
COWL "B" CONTROL
24 KEY HEX KEYBOARD
PUMP MOTOR ON/OFF
HAULAGE MOTOR SPEED
COWL 'A' CONTROL
COAL THICKNESS SETTING
METHANE WARNING
MODE MANUAL/AUTOMATIC
METHANE O.K. 1-2 %
CONTROL POWER ON/OFF
WATER O.K./MALFUNCT.
DRUM 'A' CURRENT DISPLAY
DRUM 'B' CURRENT DISPLAY
COWL 'A' POSITION
COWL 'B' POSITION
TAIL GATE MOTOR CURRENT DISPLAY
HEAD GATE MOTOR CURRENT DISPLAY
COMMUNICATIONS
CONTROL AND DISPLAY COMMUNICATIONS
CONTROL AND DISPLAY CONSOLE INPUT/OUTPUT
CONTROL AND DISPLAY CONSOLE PROCESSING AND CONTROL
CONTROL AND DISPLAY CONSOLE POWER SUPPLY
ROOF SUPPORT COMMUNICATIONS
ROOF SUPPORT INPUT/OUTPUT
ROOF SUPPORT PROCESSING AND CONTROL
DATA
CONTROL
VOICE
VERTICAL RAM DRIVE
HORIZONTAL RAM DRIVE
CONTROL OUTPUTS
CONTROL POWER ON/OFF
MANUAL/AUTOMATIC
VERTICAL RAM POSITION
HORIZONTAL RAM POSITION
HYDRAULIC PRESSURE
CONTROL POWER FROM CID CONSOLE
THE BENDIX CORPORATION
AUTOMATED LONG WALL GUIDANCE AND CONTROL SYSTEM BLOCK DIA.
3401319

Figure 4-7

drawings generated include hardware positioning and interconnects of all major subsystems, in context.

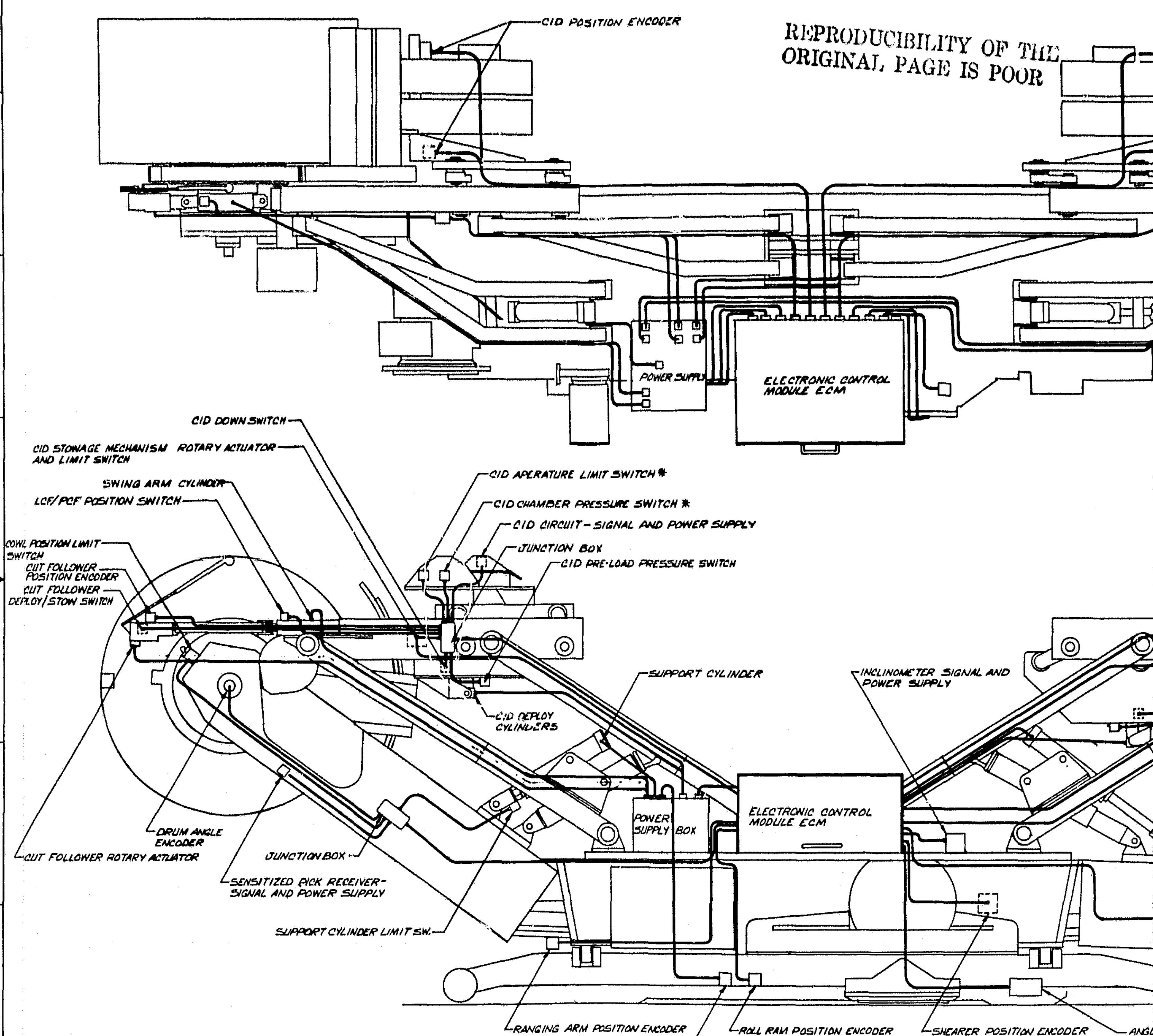
Figure 4-8 indicates the location of the ECM and its power supply, the approximate location of the sensors and control devices, and their respective cables and approximate routing. A portion of the cables shown will be routed inside the machine plating and all exposed cables will be covered with protective conduit or shielding as required to adequately protect them.

Figure 7-1 indicates the location of the MCS and its power supply. This drawing will indicate where sensor inputs are supplied to the MCS and the connections to the control devices. Cable routing is shown in this drawing where practical to do so.

Figure 4-9 indicates the location of the YAS on a roof support. As much of the cable routing as practicable is shown on this drawing. This drawing will show the approximate location of the YAS sensors and control devices.

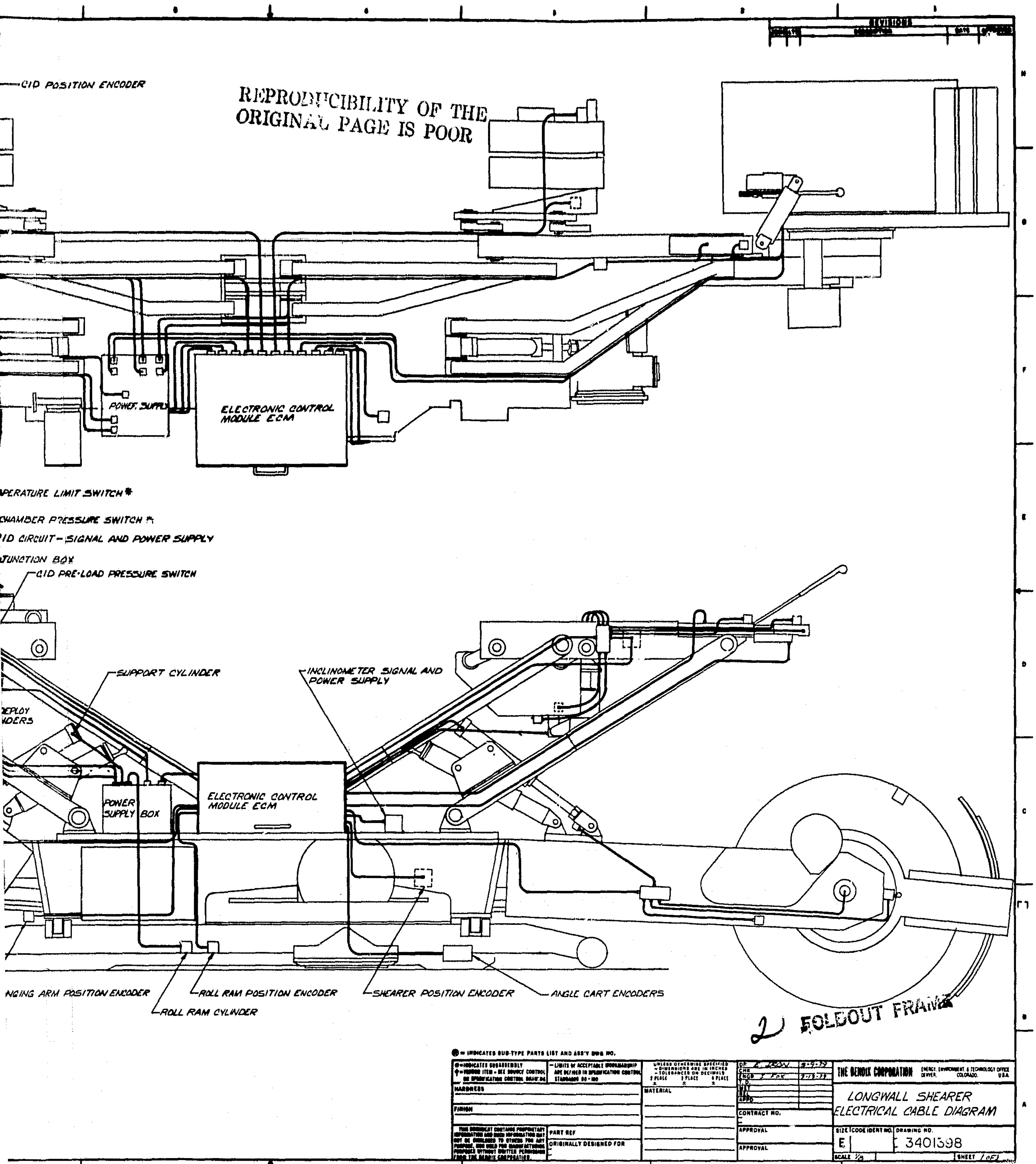
The ECM, MCS, and YAS boxes are bolted to the shearer, stage loader, and roof support as shown in the respective drawings. Shock absorbing feet will be employed where required to absorb a portion of the vibrations encountered during operation. Should a drilling and bolting operation not be practical, for whatever reason, a bracket will be welded to the respective equipment and be employed to bolt the devices.

The power supply boxes, being an explosion proof box, are bolted to the shearer and stage loader. No power supply box is required for the YAS on the roof supports since their power is obtained from the MCS power supply box mounted on the stage loader. Both power supply boxes and the control boxes are water and dust proof to prevent contamination of the electronics by the water spray and dust present on the longwall face. All of the high energy control elements which cannot be made intrinsically safe are mounted in the



* USED WITH ACTIVE NUCLEONIC CID ONLY
NOTE: SENSORS SHOWN ON THIS SIDE OF SHEARER ARE DUPLICATED ON OTHER SIDE.

FOLDOUT FRAME



2 FOLDOUT FRAME

Figure 4-8

PART NO

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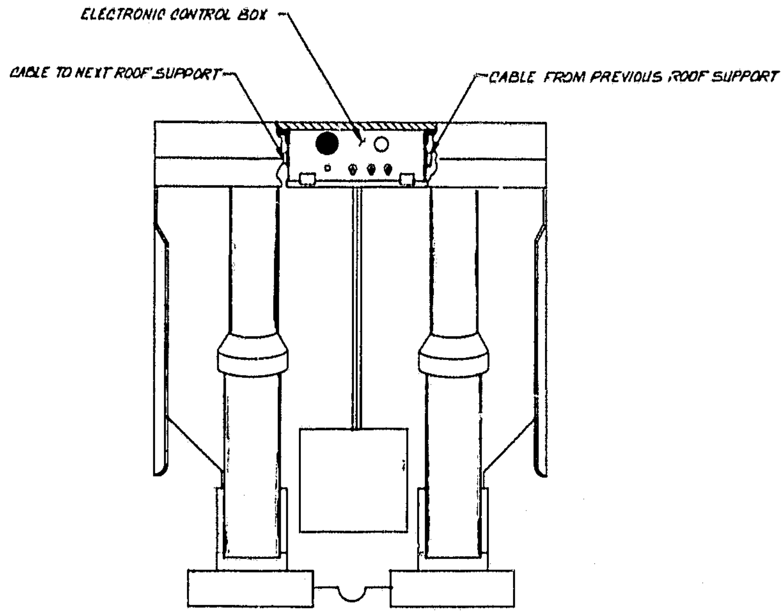
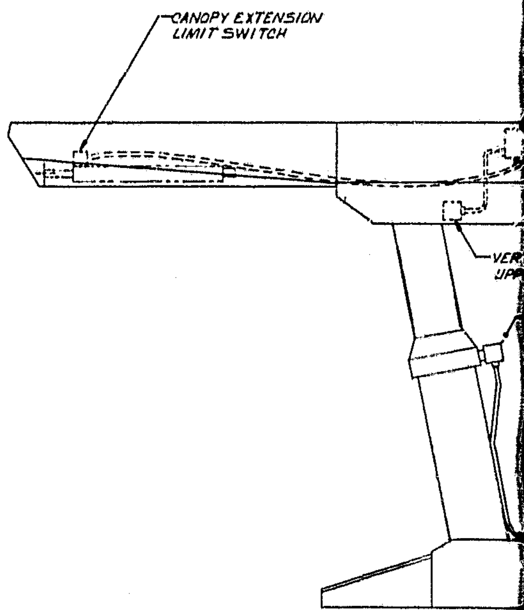




FOLDOUT FRAME

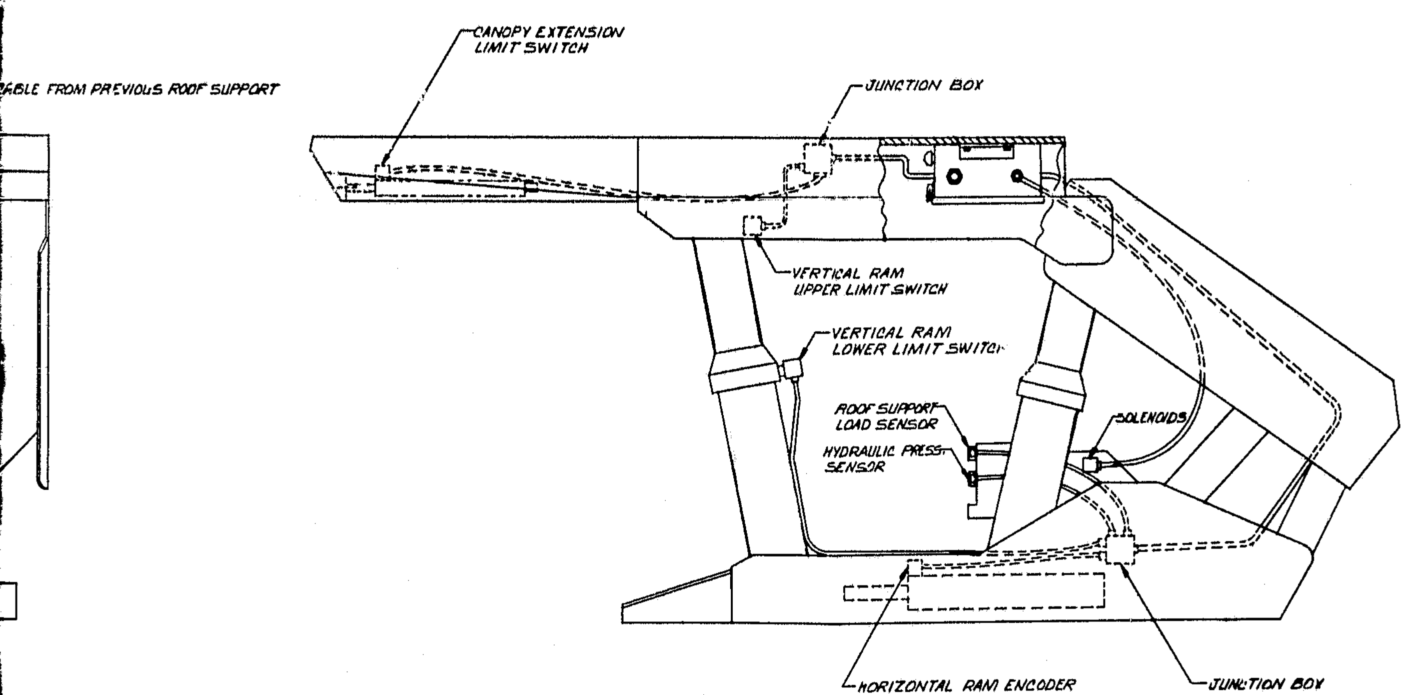
☐ DO NOT MARK PART NO.
☐ MARK PART NO. AS SPECIFIED

⊛ = INDICATES SUB-TYPE PARTS LIST

⊕ = INDICATES SUBASSEMBLY
♦ = VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING

HARDNESS

FINISH



THE BENDIX CORPORATION ENERGY, ENVIRONMENT, & TECHNOLOGY OFFICE DENVER, COLORADO, U.S.A.

ROOF SUPPORT
ELECTRICAL CABLE DIAGRAM

SIZE E | DRAWING NO. 3401503

Figure 4-9

explosion proof Power Supply Boxes. The outputs of the power supply box are either redundantly current limited to intrinsically safe levels or employ mine permissible explosion proof cables operating through packed glands. The ECM, MCS, and YAS boxes are configured to be intrinsically safe by maintaining power levels and energy storage devices (i.e., capacitors and inductors) within acceptable limits thus making all of the electronics permissible or intrinsically safe.

4.3.4 Safety - Precautions have been taken in the preliminary design in both control implementation and sensor application to make the automated longwall equipment and its operations safe.

4.3.4.1 Methane - The methane monitors currently employed on the shearer and support equipment as well as its present control and shutdown procedures are still used for methane protection; reference VCS report Phase II. The ECM and MCS accepts signals from the methane detectors for display on the MCS and ECM and warning. In addition to the display and warning the ECM and MCS will perform a redundant shutdown based upon methane levels $\geq$ 2%.

4.3.4.2 Fire - Fire sensors have been employed on board the shearer to detect excessive heat. Detection of excessive heat will cause the release of a fire retardant and initiate shearer shutdown. If the shearer is already shutdown the fire retardant will also be released. For details of this design see VCS report Phase II.

4.3.4.3 Roof Support Precautions - In order to provide safe penetration of the longwall mining face and roof support area by mining personnel, provisions have been incorporated within the design for access keys to be located on roof supports on each end of the longwall face. When penetration is desired a key is removed from its roof support which will disallow power to the shearer and roof support automatic or remote systems. Power can only be activated after all keys are returned to the roof support access key positions. Personnel, by procedure, are required to not enter the face area

without possession of a key.

4.3.4.4 Control Precautions - Precautions have been taken within the control algorithms to prevent hazards where possible. These hazard control algorithms follow.

1. Prior to automatic operation, all control switches on board the shearer must be in the off or neutral position. Any change from the off or neutral position will revert the shearer and MCS to manual mode.

2. Whenever the system is either shutdown, or the automatic/remote is being selected after the shearer has been in manual mode, the system will be required to go through its initialization sequence before the automatic/remote mode of operation is enabled.

3. Manual entry into the system operation from the Control and Display panel keyboard (DAS) requires the use of a controlled access key. The access to the key is limited as a procedural matter.

4.3.4.5 Mine Permissibility - The permissibility of the shearer mounted ECM power supply has been fully discussed in the VCS report. However most of the power associated with the YAS is that required to drive the roof support mounted electronics and solenoid activated valves. This power and the power required by the MCS is supplied by the MCS power supply which is mounted on the stageloader, along with the MCS. For a description/disucssion of the MCS power supply. See Section 8.

4.3.5 The Yaw Alignment System - The block diagram previously shown includes the requirements for the total longwall automation. Figure 4-10 is a block diagram of the Yaw alignment portion of Longwall Automation.

The ECM is employed to receive the angle measurements from the angle cart and compute the corrections required to maintain conveyor "straightness" within acceptable limits and perpendicular to both headgate and tailgate. The ECM is also employed to transfer the correc-

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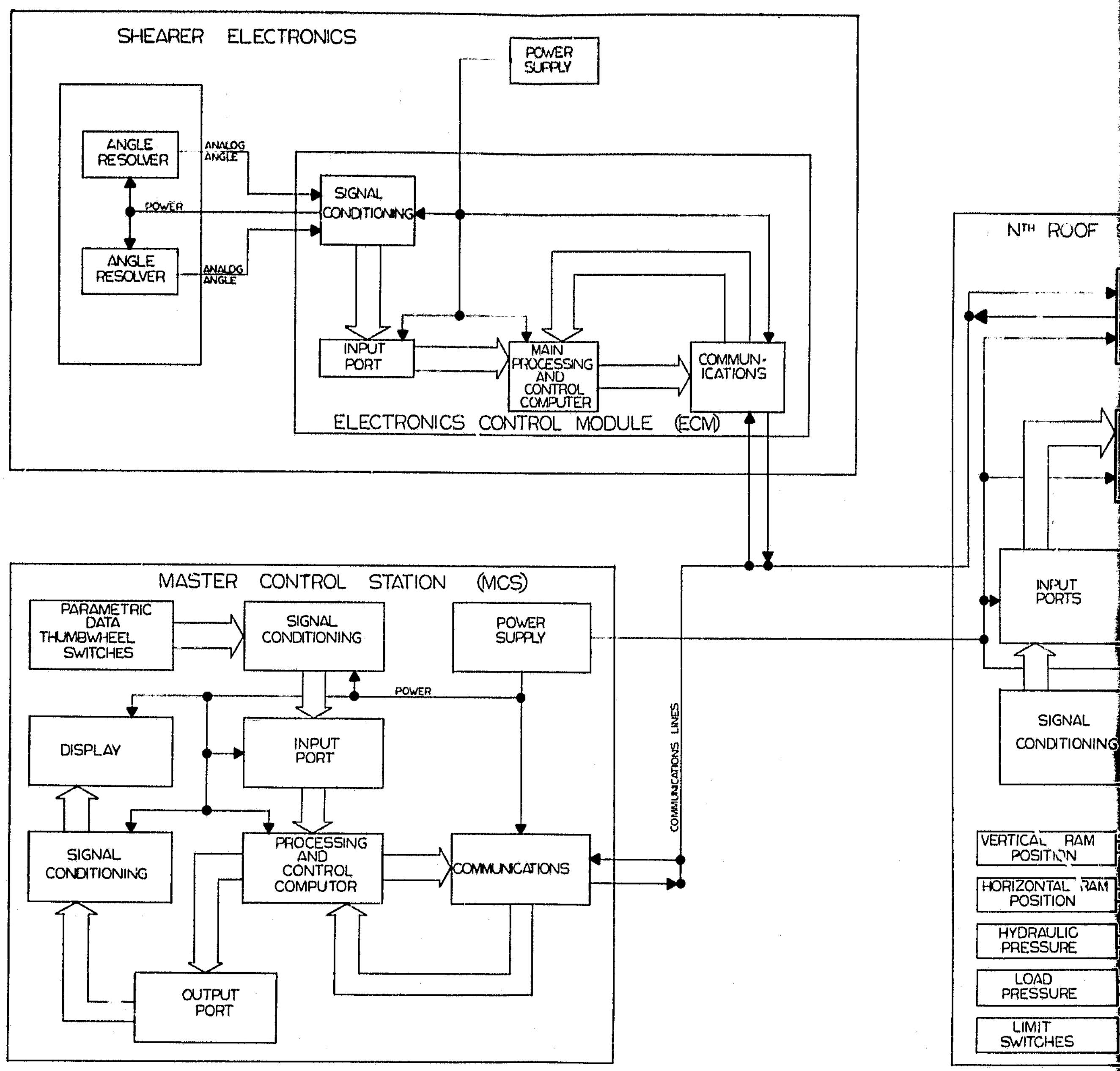

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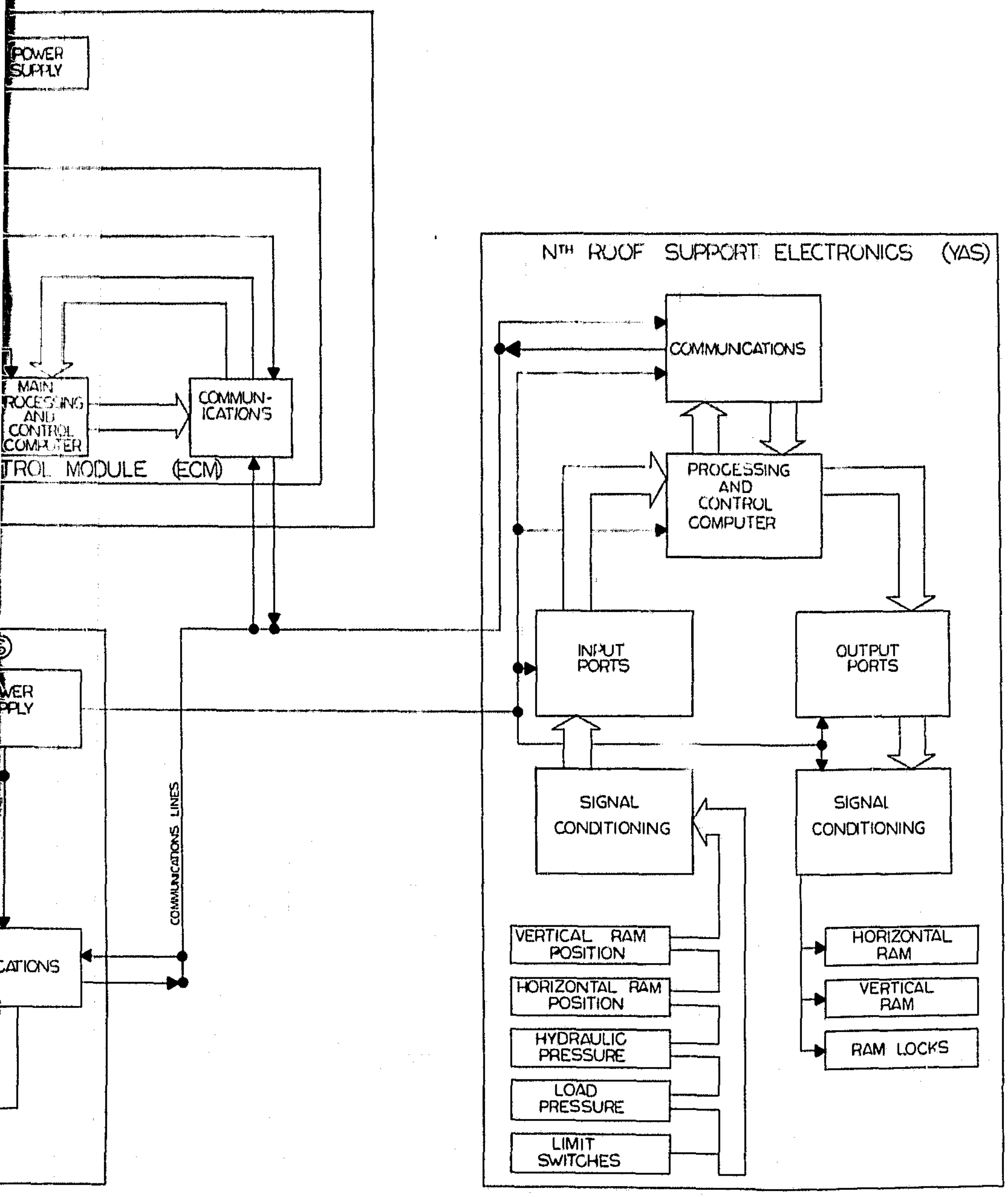

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BLOCK DIAGRAM
YAW ALIGNMENT
ELECTRONICS

SIZE E — DRAWING NO. 3401507 — SHEET 1 OF 1

Figure 4-10

tions required to the appropriate roof support, command the specific roof support to perform its respective alignment maneuver, and receive feedback from the roof support to indicate the execution of its alignment command. This preliminary design report on the Yaw Alignment system discusses the major ECM functions as they relate to the YAS.

4.3.5.1 <u>YAS Data Processing</u> - The angle cart sensor is mounted on the shearer in the approximate location as shown on the signal distribution drawing of Figure 4-8. The Angle Cart receives power from the ECM power supply. The signal cable into the ECM from the angle cart will, in addition to supplying power to the angle cart, transfer the output analog signal to the ECM box. Within the ECM box the angle cart data is routed to the signal conditioning electronics which will be buffered, transformed from analog to digital information and strobed into the processor memory at a programed rate, via the input/output ports. The main processing and control computer is employed to compute the alignment corrections for the roof supports. These corrections are sent to the MCS for display and to the specific roof support to perform the correction. The data is transfered from the Shearer ECM to the MCS and roof support (YAS) by the synchronous, multiplexed communication subsystem. The ECM receives the parametric data from the MCS it requires in calculating the yaw alignment as well as performance data from the YAS. This data transfer is also accomplished via the communications subsystem.

The input/output portion of the ECM of interest is employed to store angle cart data, digitized by the signal conditioning electronics, until the main processing and control computer acts upon the data. The input ports receive data from the signal conditioning and store it in 8 bit binary ports. At an appropriate time within the main processing and control computer algorithms, control signals are generated by the computer which place these 8 bit words, one at a time on to the 8 bit data bus for subsequent storage in the appropriate memory location within the random access memory of the microprocessor.

These words are used by the computer in its algorithms or are transferred to the MCS or the YAS via the communications portion of the ECM.

The Yaw Alignment Signal Conditioning was included within the ECM portion of the VCS report. The only portion of the ECM signal conditioning which is employed in yaw alignment is that of the Angle Cart sensor mounted on the shearer. This signal conditioning consists of 10 bits of position information, being received by line receivers, then buffered and stored into latches for reading by the input ports and used by the processing and control computer. Note should be made, at this point, how the Angle Cart sensors produce an analog signal which converted to 10 bits of digital data on board the Angle Cart. This signal path is shown on Figure 4-20 of VCS report Phase II and is not reproduced here.

4.3.5.2 YAS Communications - The communications portion of the ECM system is a micro-processor based subsystem employed to transfer voice and data from the shearer to the MCS and the roof support electronic subassemblies. This voice and data link also provides for the voice and data from the control and display console to the shearer and from the roof supports to the shearer. YAS control is exercised via this communications link.

The communications subassembly provides the mechanism for loading initial constants into the random access memory of the main processing and control computer for both shearer and YAS control. These constants are generated and stored in the processor located in the control and display console. The communications subsystem also provides the mechanism for interrogation of the shearer or roof support from the Master Control Station (MCS).

This communications subassembly was discussed fully in the VCS report Phase II. This discussion is reproduced for convenience in Appendix A of this report.

4.3.5.3 YAS Roof Support Functions - The Electronics module on the individual roof supports, reference Figure 4-13, provides an interface between the sensors and solenoids on the roof supports and the common communications data bus to the VCS and to the MCS. The basic functions performed at the roof support by this module are:

Operation of Vertical Ram
Operation of Horizontal Ram
Operation of Canopy Ram

Basic functions monitored by the electronics in this module are:

Current Sensor
Hydraulic Pressure Sensor
Vertical Ram Encoder
Horizontal Ram Encoder
Load Cell
Vertical Ram Limit Switches
Canopy Limit Switch
Local Drive Switches

This module is employed to receive the Yaw alignment correction data from the ECM on board the shearer and at a commanded time execute those operations required for advancing the conveyor towards the coal face, in such a way as to maintain conveyor straightness within acceptable limits and perpendicular to the head and tailgates.

The sensors used to monitor roof support functions consist of horizontal and vertical ram position sensors mounted on the roof support along with pressure sensors and limit switches. These sensors and switches along with the control electronics, receives power from the MCS Power Supply. The sensor and switch data is routed to the signal conditioning electronics in the roof supports, reference Figure 4-11. It is then buffered and stored for processing through the input ports and into the processor memory for use by the processing and control computer, reference Figure 4-12. This data is then employed

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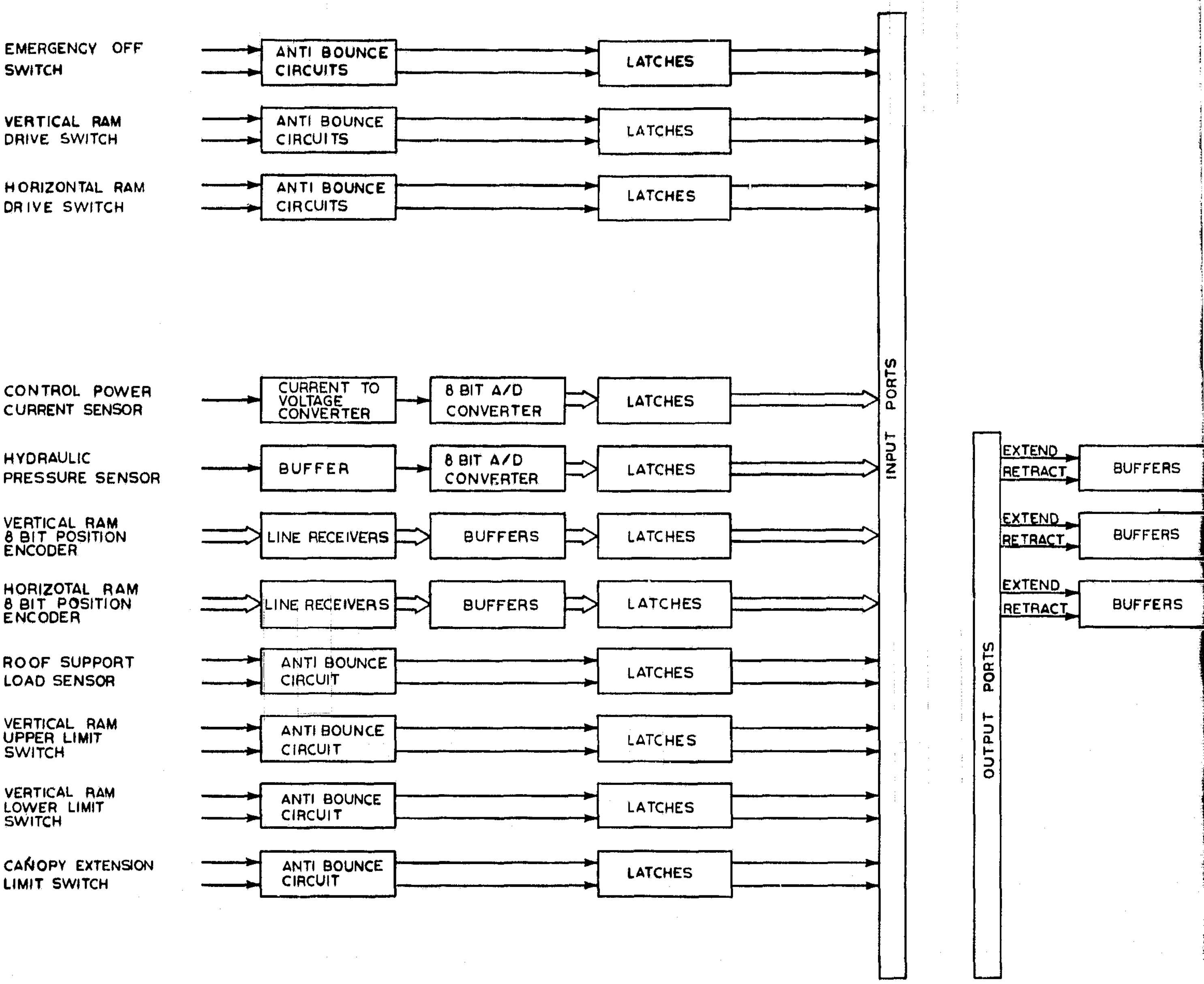

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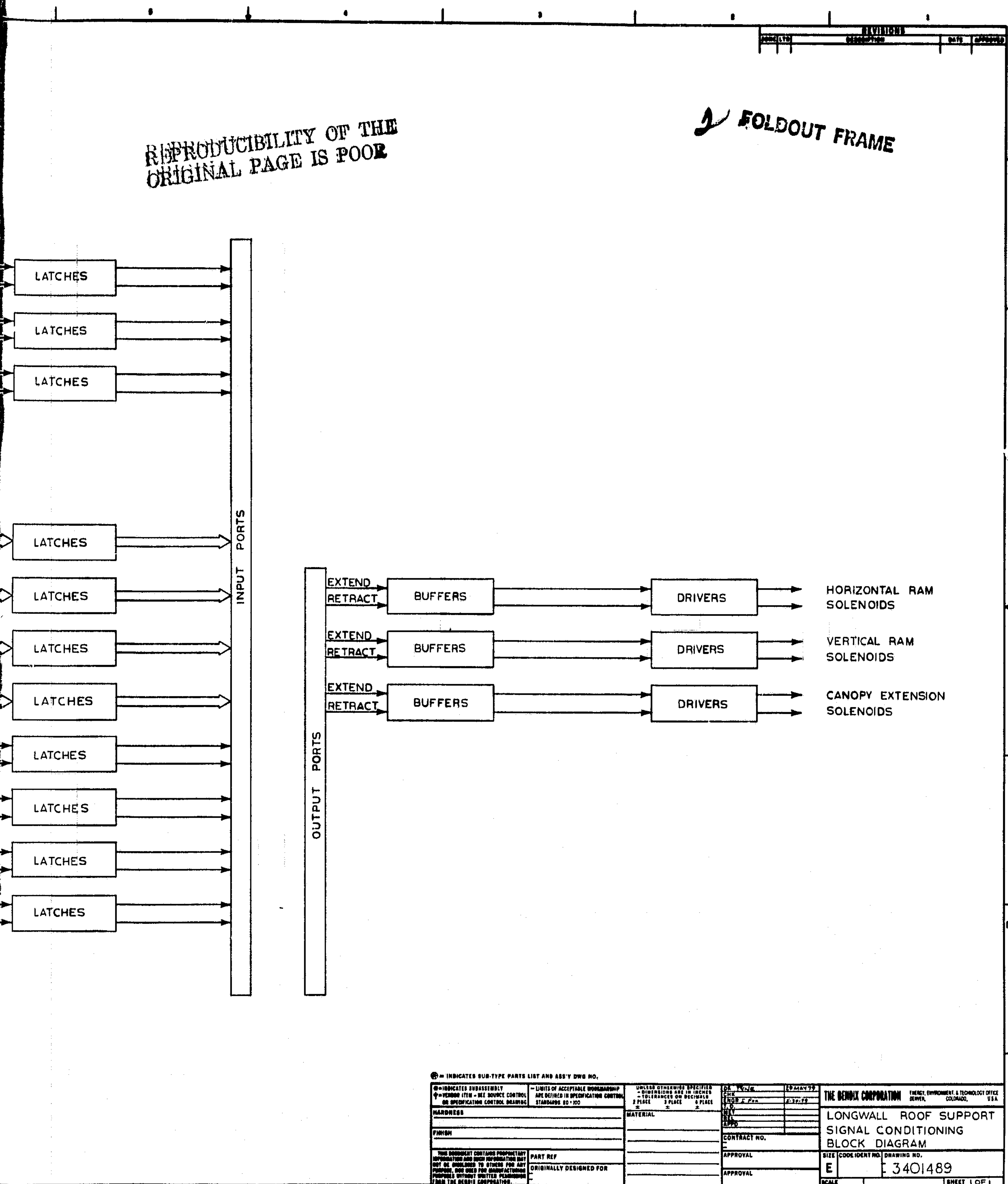
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OUTPUT PORTS
EXTEND
RETRACT
BUFFERS
DRIVERS
HORIZONTAL RAM
SOLENOIDS
EXTEND
RETRACT
BUFFERS
DRIVERS
VERTICAL RAM
SOLENOIDS
EXTEND
RETRACT
BUFFERS
DRIVERS
CANOPY EXTENSION
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THE BENDIX CORPORATION
LONGWALL ROOF SUPPORT
SIGNAL CONDITIONING
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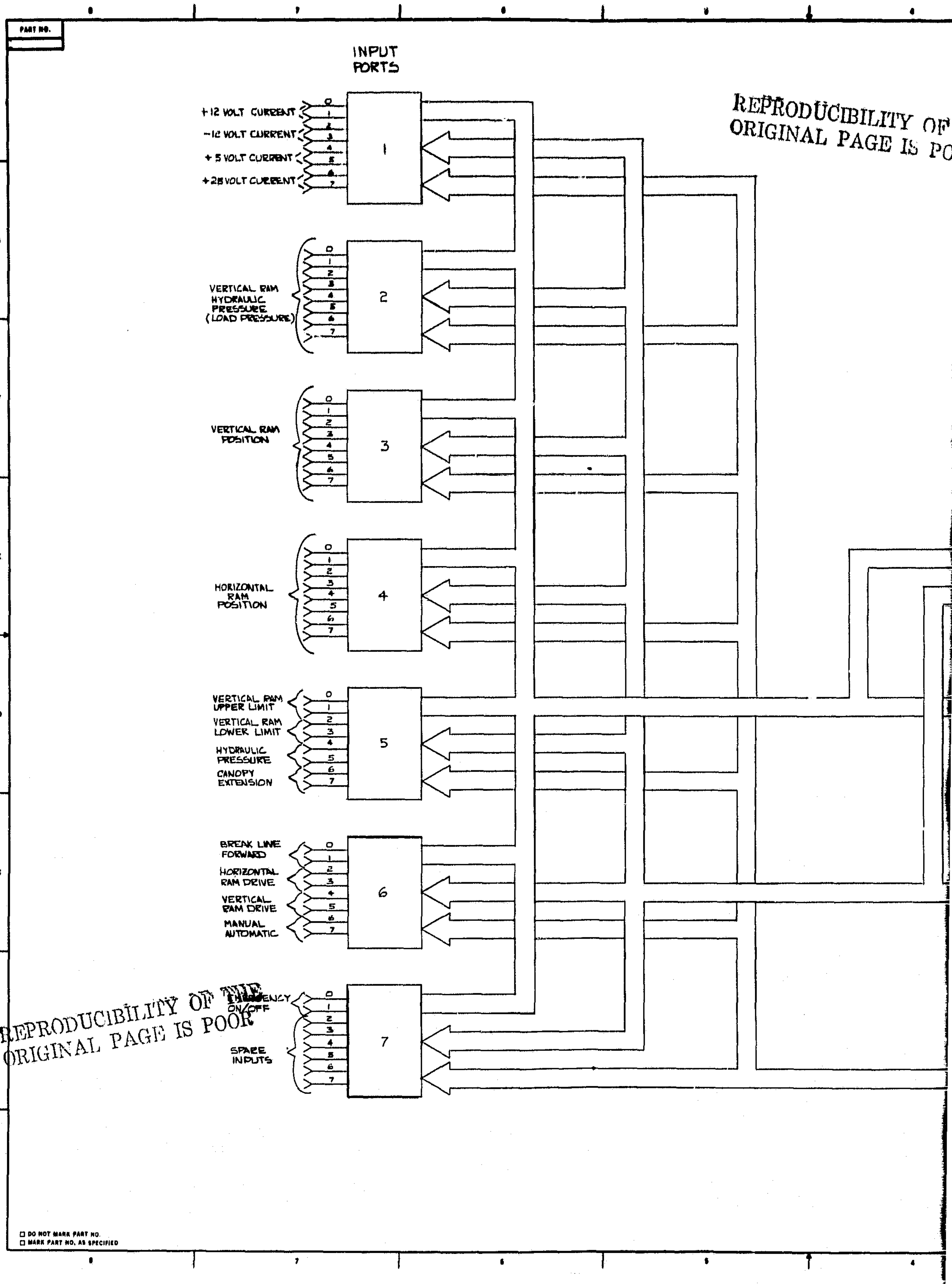
Figure 4-11


PART NO.
INPUT PORTS
+12 VOLT CURRENT
−12 VOLT CURRENT
+5 VOLT CURRENT
+28 VOLT CURRENT
VERTICAL RAM HYDRAULIC PRESSURE (LOAD PRESSURE)
VERTICAL RAM POSITION
HORIZONTAL RAM POSITION
VERTICAL RAM UPPER LIMIT
VERTICAL RAM LOWER LIMIT
HYDRAULIC PRESSURE
CANOPY EXTENSION
BREAK LINE FORWARD
HORIZONTAL RAM DRIVE
VERTICAL RAM DRIVE
MANUAL AUTOMATIC
ON/OFF
SPARE INPUTS
1
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3
4
5
6
7
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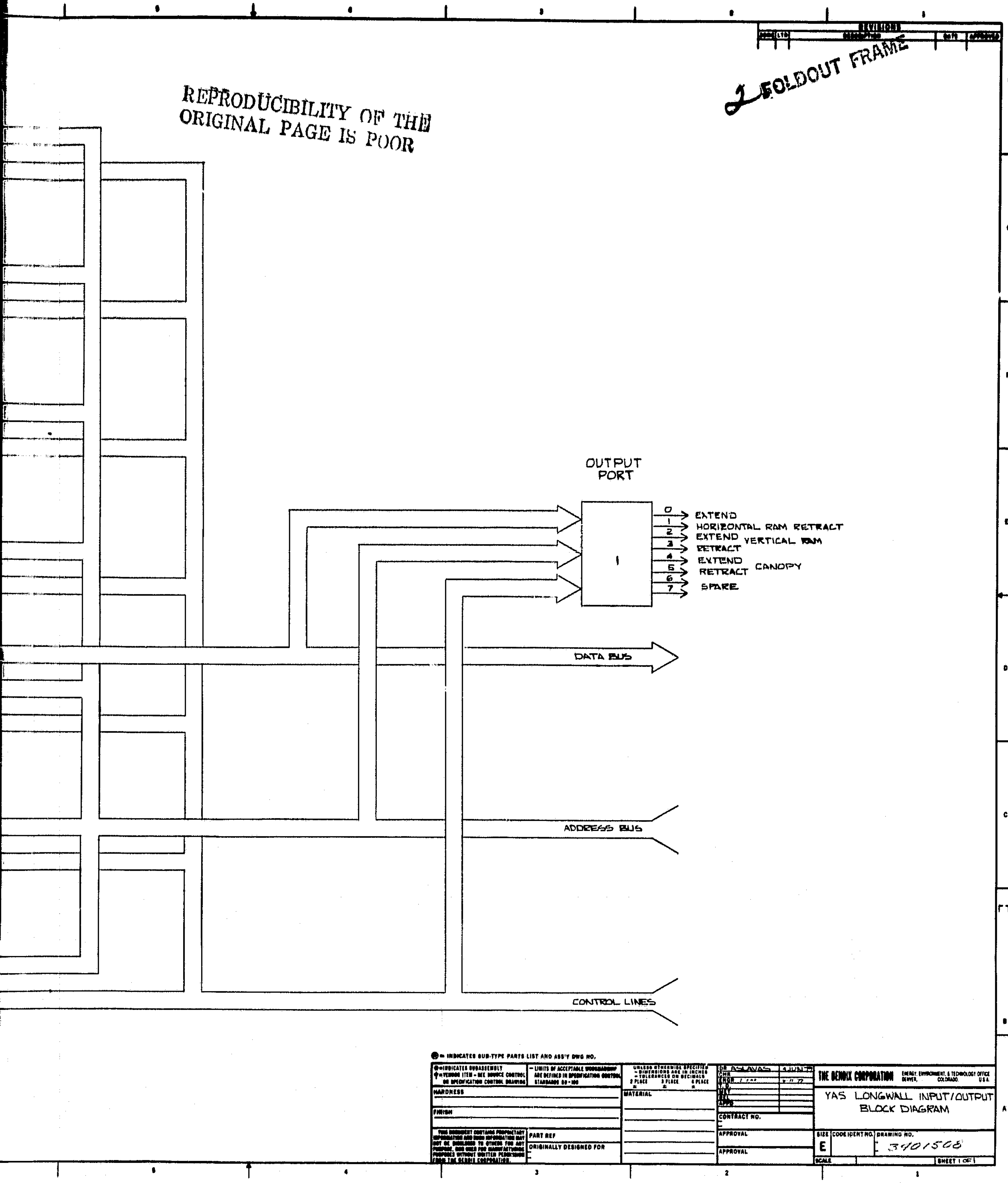
OUTPUT PORT
1
0 EXTEND
1 HORIZONTAL RAM RETRACT
2 EXTEND
3 RETRACT
VERTICAL RAM
4 EXTEND
5 RETRACT
CANOPY
6
7 SPARE
DATA BUS
ADDRESS BUS
CONTROL LINES
REVISIONS
THE BENDIX CORPORATION
ENERGY, ENVIRONMENT, & TECHNOLOGY OFFICE DENVER, COLORADO U.S.A.
YAS LONGWALL INPUT/OUTPUT BLOCK DIAGRAM
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Figure 4-12

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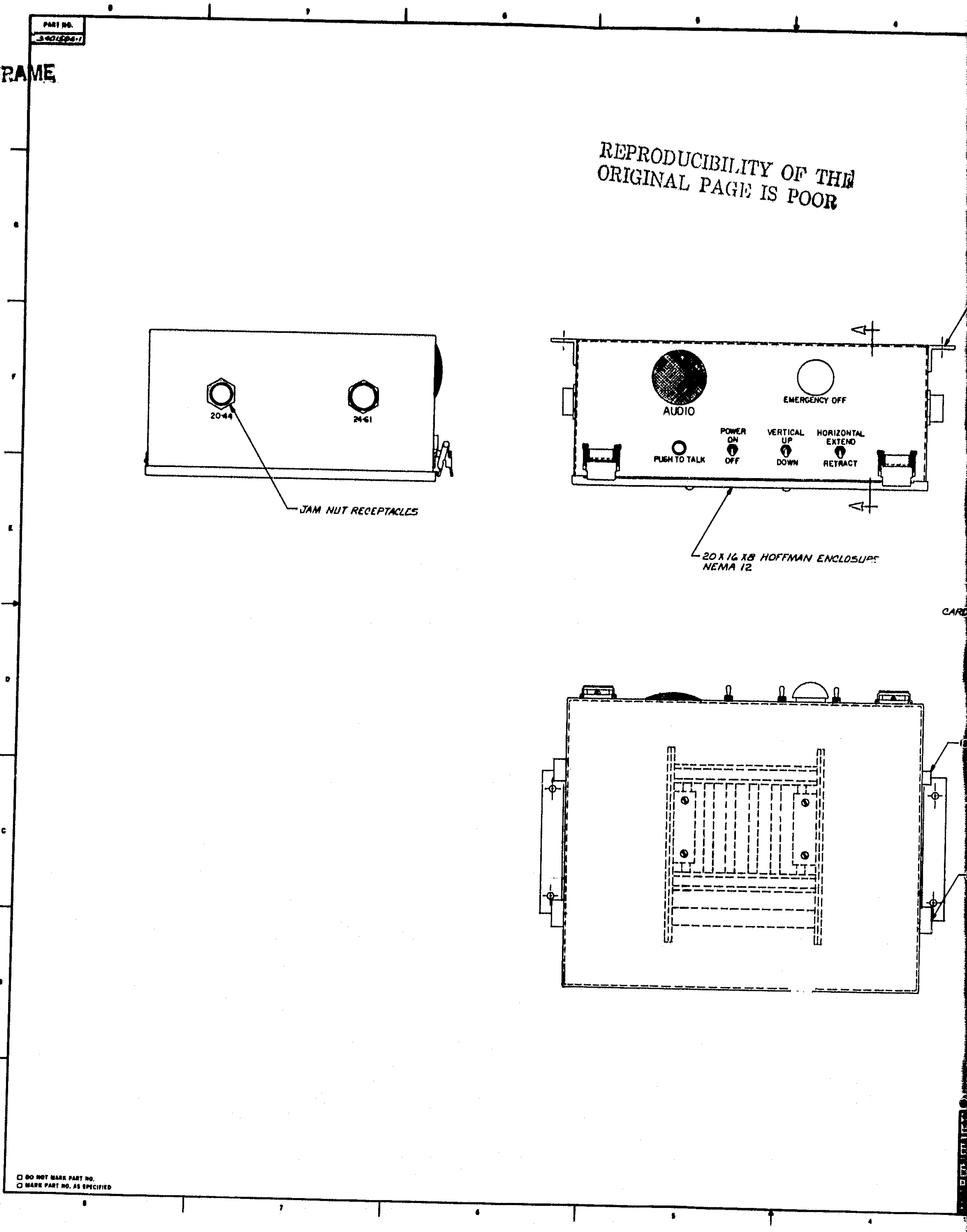

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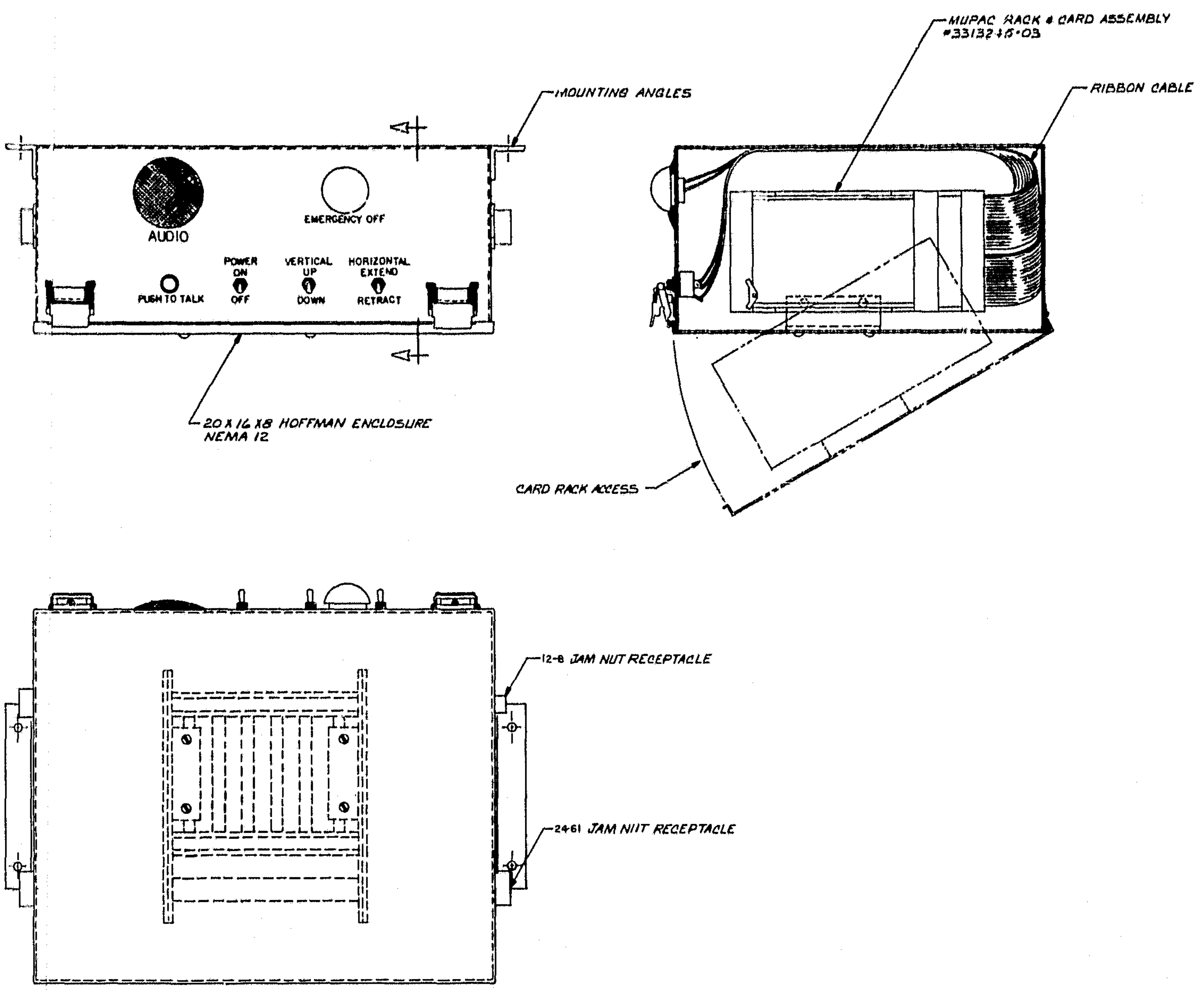

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LONGWALL YAS
ELECTRONIC CONTROL BOX

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SCALE 1/2

Figure 4-13

by the processing and control computer as control feedback in addition to being transfered to the MCS for display and to the ECM for system analysis, reference Figure 4-14. This module receives yaw alignment information from the ECM via the communication subsystem. This communications system also provides the mechanism by which the YAS may be commanded to perform the alignment advance sequence. The communications subsystem also provides the mechanism for exercising the roof supports from the MCS during checkout. The commands for control of the hydraulic rams, both Horizontal and Vertical, are generated within the processor and its output ports via the signal conditioning electronics.

4.3.5.4 YAS Functions in ECM Box - The Electronic Control Module (ECM) on the shearer contains elements of the YAS system. most of the functions contained within this box are covered in some detail in the VCS report Phase II. The microprocessor used in the YAS control algorithm during the turn around and angle card sequence is the same microprocessor used with the linkup monitor to operate shearer control functions during traverse. This microprocessor reads the Angle Cart data, calculates yaw alignment corrections and transmits data and execution orders to the roof supports. This microprocessor also exchanges status and data with the MCS.

4.3.5.5 YAS Function In The MCS - The MCS is the basic status monitoring and remote control and data entry mechanism to the YAS system. Its functions are discussed in detail in Section 7 and will not be repeated here.

4.4 Hardware Partitioning - The hardware methods and techniques used to implement the YAS in the roof supports, in the ECM and in the MCS are very similar. Certain of the circuit boards, indeed, will, as a design goal, be interchangeable in the system.

The micro processor in the roof supports (Figure 4-14), the microprocessor in the ECM (Figure 7-20) and the microprocessor in the MCS

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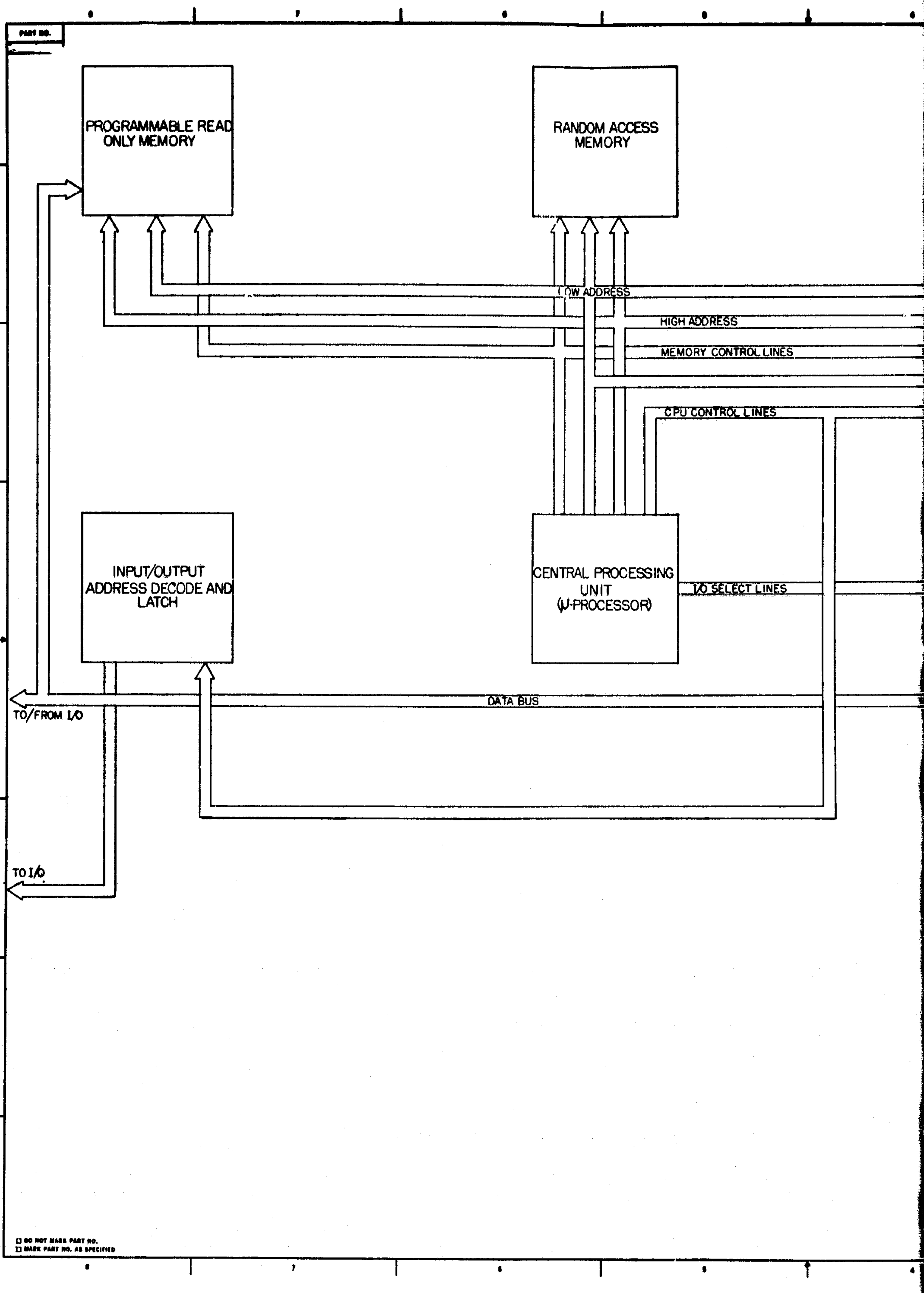

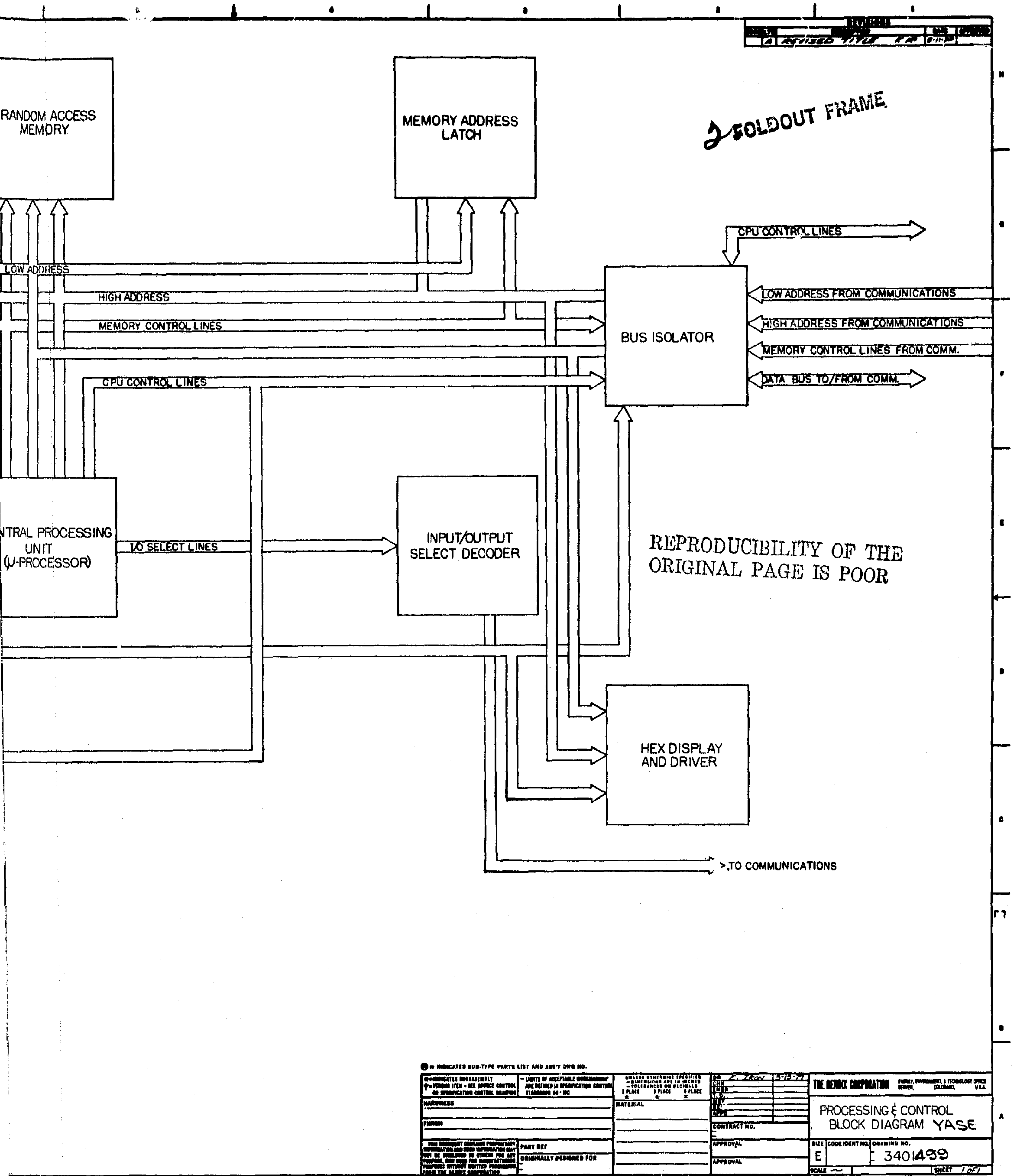
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RANDOM ACCESS MEMORY
MEMORY ADDRESS LATCH
CPU CONTROL LINES
LOW ADDRESS
HIGH ADDRESS
MEMORY CONTROL LINES
CPU CONTROL LINES
BUS ISOLATOR
LOW ADDRESS FROM COMMUNICATIONS
HIGH ADDRESS FROM COMMUNICATIONS
MEMORY CONTROL LINES FROM COMM.
DATA BUS TO/FROM COMM.
NTRAL PROCESSING UNIT (μ-PROCESSOR)
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INPUT/OUTPUT SELECT DECODER
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PROCESSING & CONTROL BLOCK DIAGRAM YASE
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3401499

Figure 4-14

(Figure 7-20) are similar boards and, with the ALU unit and memory chips made optional, may attain a high degree of interchangeability in their implementation.

The input/output requirement of the microprocessor in the ECM, as far as the Yas Alignment System is concerned, is simply to interface the Angle Cart and to operate with the communication link. The I/O requirement on the roof support portion of the YAS is to interface the roof support solenoids and sensors and to operate the communications link.

The I/O requirement of the MCS portion of the YAS system is to interface the displays and switches on the MCS and to operate the communications link.

Since access to the communications link is a common design requirement in all three applications,it is probable that this function can be partitioned into a single board design and replicated so as to obtain the benefits of interchangeability. The operation of this communications subsystem is detailed in the VCS report Phase II and is included in this report as Appendix A.

The portion of the I/O system that does not utilize the communications link differs substantially in the three portions of the YAS system. It is because of this that signal conditioning and port structure are shown independently. The detail of the ECM signal conditioning and port structure is largely contained in the VCS report Phase II. Detail of the port structure and signal conditioning of the roof support package is contained in Figure 4-11 and Figure 4-12. The detail of the signal conditioning and port structure for the MCS is shown in Figure 7-18 and Figure 7-19 of this report.

4.4.1 <u>Electronic Design</u> - The interconnection of the three physically partitionable section of the YAS is as shown in Figure 4-10. Wherever possible the design is implemented with Cmos logic elements. The microprocessor family most suitable to this application at this

time appears to be the 1800 series family Cmos. The compatible logic family of supporting elements is the series 4000 Cmos. Certain of the signal conditioning circuit elements in all three section of the YAS will most probably be implemented with low and medium power TTL logic elements. This is necessary to efficiently obtain drive power to the solenoids and displays to which the system logic must interface.

Because of the necessity to obey the constraints of mine permissibility and intrinsic safety, the electronic design is sensitive to power consumption. One of the major advantages of the Cmos approach to the design is that it affords a very power efficient hardware implementation.

The microprocessor approach is specified for this application largely because of its unique suitability to the control requirements of the system design. The memory elements, port structure microprocessor and other systems chips are second and third generation microprocessor ships specifically developed to provide the systems engineer with a powerful means to solve problems involving the control of machinery and external devices. These chips can also easily perform elementary calculations required to process sensor data. The scaling, limit checking and code conversion operations incident to reading sensors, operating displays and controling solenoids are easily and conveniently handled by the microprocessor.

This systems design of the Yaw alignment system does require that more extensive calculations be performed upon the raw data measured by the Angle Cart. These calculations, while simple in principle, are quite beyond the capability of the microprocessor when operating in the real time environment of the control algorithms. For this reason arithmetic logic unit (ALU) chips are added to the normal control configurations of the 1800 series microprocessor, the ALU chip is a highly specialized device capable of performing high speed mul-

tiplications and divisions in floating point notation upon simple command form the microprocessor. Typical of the chips from which the design engineer may select is the AM9511 manufactured by Advanced Microdevices.

It is assumed that the data output from the Angle Cart will be an analog differential voltage from a reasonably low impedance source whose value is proportional to the angular inputs to the Angle Cart resolvers. In the signal conditioning portions of the ECM logic this voltage is converted into a 10 bit one's complement digital representation which can then be maninultaed by the calculation algorithms of the microprocessor. The A/O converters, instrumentation amplifiers and sample and hold circuits form part of the ECM signal conditioning circuitry necessary to the operation.

A number of additional supporting chips felt to be suitable for this hardware implementation are discussed in Section 7 of this report and are not presented here.

4.4.2 Packaging Design - The electronics requirement of the roof support portion of the YAS is contained within an electronics enclosure shown in Figure 4-13. The electronics within the box is intrinsically safe.

The YAS enclosure is a 20" x 16" x 8" inches, Nema 12 oil and dust tight steel enclosure. The box need not be "explosion proof" since all the electronics contained in it and all the supply voltages and currents are "intrinsically safe". The box has 4 industrial grade, oil and dust tight connectors which interface with sensor, solenoids, and other roof supports, as shown in Figure 4-9, YAS Electrical Cable Diagram.

The YAS electronics inside the box are packaged on 4 x 8 wire-wrap component boards. There are 4 cards that mate to a card cage assembly which is mounted on the hinged cover of the box, for easy access. The YAS Control Box is mounted at the bottom of each roof support. These boxes are identical and, therefore, can be interchanged on any roof support. Each YAS Control Box receives power to operate the electronics and solenoids from the MCS power supply box. The power, as well as communication line, is routed from the MCS to the first roof support YAS Control Box and then cascaded to the next roof support YAS Control Box and soon.

The electronics requirement for the ECM portion of the YAS is contained within the ECM itself on board the shearer. details of this packae design are discussed in VCS report Phase II and are not repeated here.

The electronics requirement for the MCS portion of the YAS is contained within the MCS. Supporting detail on this package design is given in Section 7.6 and is not repeated here.

4.4.3 <u>YAS Mounting and Cabling</u> - The ECM Electronics are mounted on the shearer as shown in Figure 4-8. The roof support electronics is mounted on the roof support as shown in Figure 4-9. The MCS portion of the YAS electronics are as shown in Figure 7-1. Power supplies for the YAS are shown in Figure 7-1.

Signal intercabling between the MCS and the ECM is by matched terminated line. These lines contain the low voltage subcarriers generated by the communications link.

Signal intercabling between the MCS and the roof supports consists of a matched terminated line from its geometric location on it.

Signal intercabling between the ECM and the Roof supports is by matched terminated line similar to the MCS to roof support terminated line.

Details of bus cable routing, line termination, impedance level, power levels noise rejection etc. will be defined in detail design to minimize cable length and complexity.

SECTION 5

ROLL CONTROL SYSTEM

5.1 FUNCTIONAL DESCRIPTION

The function of the roll control system is to provide an additional degree of control for the shearer. The shearer is equipped with hydraulic actuators which allow it to be rotated about its longitudial axis, thus tilting both of the shearing drums relative to the coal seam. The purpose of roll control is to provide the capability to correct for twists and modulations in the conveyer. These twists can occur when coal or other debris becomes lodged under the conveyer.

The baseline roll control system uses a roll sensor to measure the roll angle of the shearer relative to the local vertical. This signal may be biased to allow for operation in coal seams which are not level. The hydraulic actuators are commanded by the roll error angle at sensor output, through the necessary compensation. This control system is intended to be active, that is, to provide continuous control along the face during the shearing operation. The additional degree of freedom offered by roll control can be beneficial in maintaning the shearer within the coal seam.

Alternative roll control concepts are viable. Mounting a roll sensor -- (an inclinometer) -- on a separate cart will provide the necessary roll information and will eliminate vibrational noise existing when the inclinometer is measuring the roll angle and the shearer is cutting coal simultaneously. Roll commands are generated from the inclinometer output to control the shearer on the next cut.

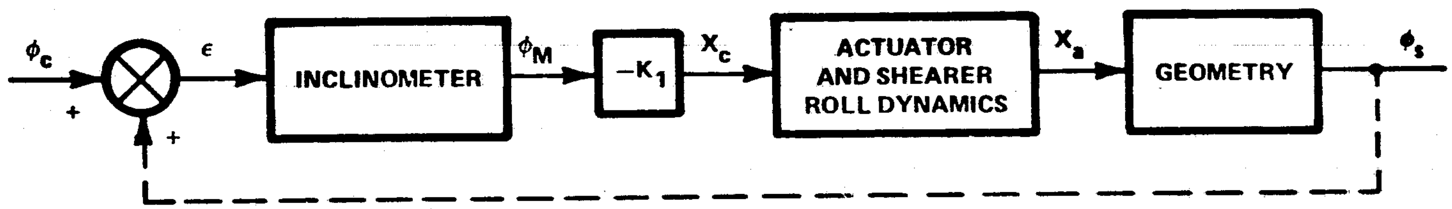
Other roll control concepts include mounting inclinometers on the conveyor proper and on the roof supports, mounting the inclinometer on the shearer but stopping at various points and measuring the roll. Detailed descriptions of these roll concepts follow.

5.2.1 Roll Control System Implementation

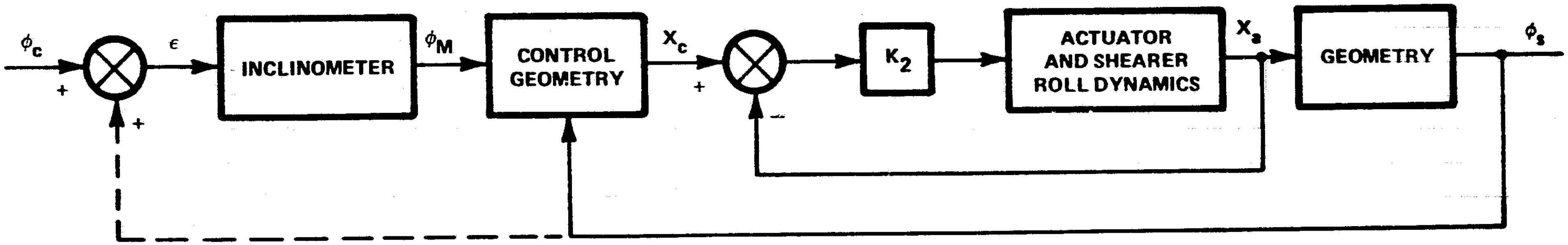
Two baseline configurations were considered for the implementation of active roll control. These systems differ in the treatment of the roll sensor and actuator in the control loop. Figure 5-1 illustrates the two loop configurations used in this study. Here, the roll sensor is an inclinometer. The system at the top of this figure is referred to as the open actuator loop, and the system at the bottom is referred to as the closed actuator loop. This nomencalture refers to the treatment of the hydraulic actuator relative to the control loop.

Since the system is intended to be active during shearing operations, it will be subject to vibrational distrubances which will effect its performance. The inclinometer used as a roll sensor relies on gravitational acceleration to detect roll angles and, therefore, any vibrational accelerations along the sensitive axis of this device are interpreted as roll signals and thus represent noise in the system. This problem was addressed in the design and specification of the control loops in the VCS report.

The open actuator loop system uses the inclinomenter to sense the sum of the roll of the conveyor ϕ_C and the roll of the shearer ϕ_S (see Figure 5.2). This signal drives the actuators through the compensation K_1, which was discussed in Reference 1. With this system, the inclinometer is actively within the control loop and, therefore any filtering required to reduce noise levels will potentially effect loop stablity. The closed actuator loop system is an alternative solution intended to provide a means of filtering inclinometer data without affecting the



OPEN ACTUATOR LOOP



CLOSED ACTUATOR LOOP

Figure 5-1. Baseline Roll Control System

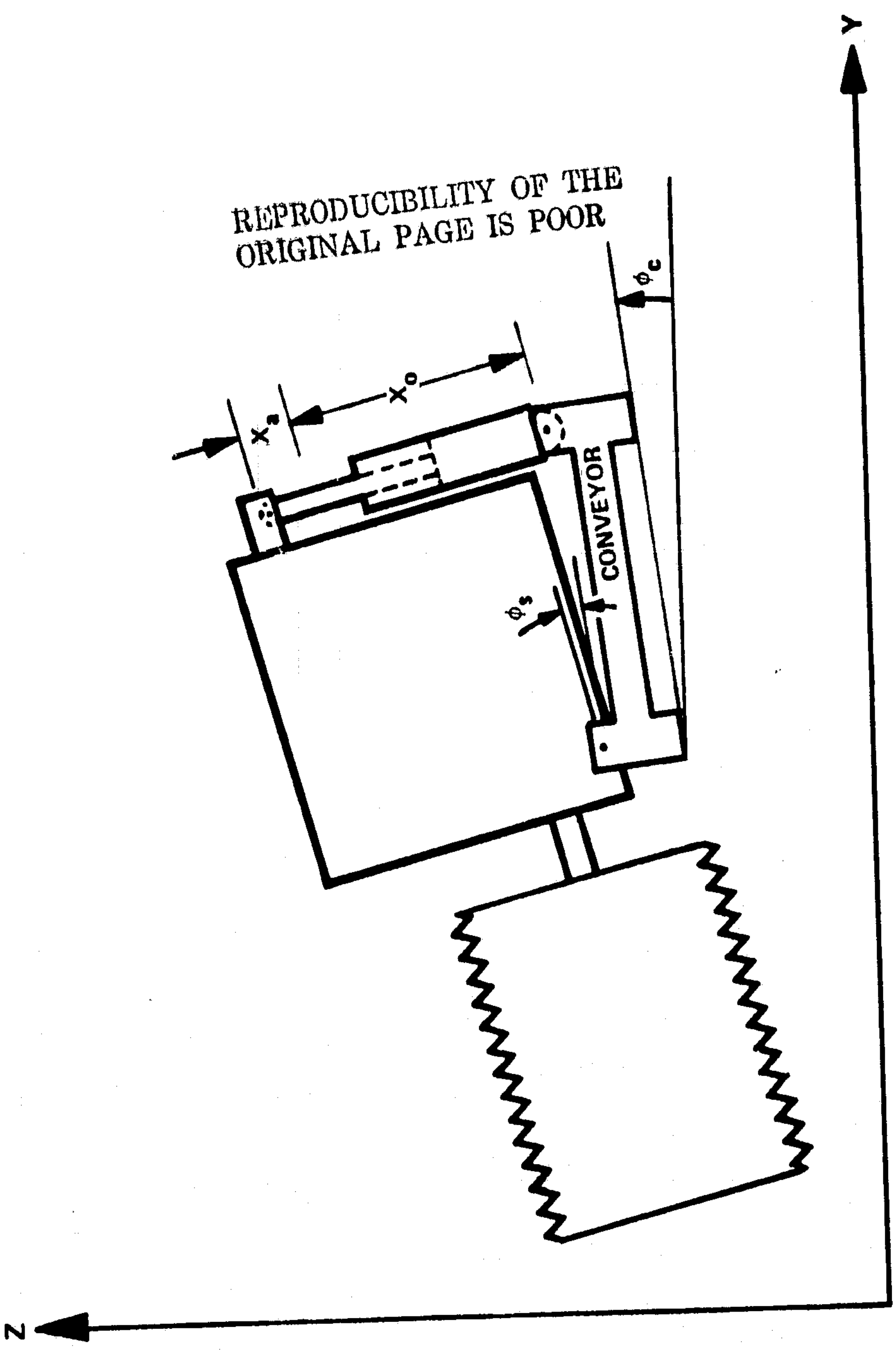


Figure 5-2. Roll Geometry

control loop. A position loop was closed around the actuator as was done for the vertical control system. The inclinometer is outside of this primary loop, and therefore, acts as a reference to update the actuator loop.

5.2.2 Inclinometers Mounted on a Separate Cart

An alternate roll control concept is one where the inclinometer is mounted on a separate cart. The separate cart is moved along the conveyor and the output of the inclinometer is sampled at some regular frequency. A straight line is fitted between these sampled measurements to obtain the measured roll profile ϕ_{MS}. This roll profile is played in as a command to the shearer roll system on the next cut.

5.2.3 Inclinometers Mounted on Conveyor Proper

Another roll control concept is one where inclinometers, mounted on the conveyor proper, measure the conveyor roll at various points. A straight line is again fitted between measurements. The shearer roll system is then commanded in the same way as the concept with the inclinometer mounted on a separate cart.

5.2.4 Inclinometers Mounted on Roof Supports

Another roll control concept is one that uses inclinometers mounted on the roof supports. These inclinometers can be used to determine the conveyor roll profile on the previous advance. The shearer roll is commanded with the roof support inclinometers in the same manner as with the conveyor proper inclinometers by assuming that the roll profile has not changed appreciably from the previous advances.

5.2.5 Inclinometers Mounted on Shearer-Measure While Cutting on the Clean-Up Pass

Another shearer mounted inclinometer roll control concept is one involving mode of operation. The inclinometer measurements are made when cutting on the clean-up pass. This concept is the same as the baseline concept except that the vibrational noise on the clean-up cut will be considerably smaller than when measuring at the same time the shearer is cutting. After measuring and cutting on the clean-up pass, the conveyor is advanced and the shearer roll is held to zero during the actual cut.

5.2.6 Inclinometers Mounted on Shearer -- Measure Without Cutting on Cleanup Pass

Another roll control concept considered is a shearer mounted inclinometer that measures roll without cutting on the clean-up pass. The shearer roll angle ϕ_S is held at zero while measuring so that the inclinometer measures the conveyor roll. The roll profile command for the next cut is obtained by adding the shearer roll angle ϕ_S on the last cut to the inclinometer output before sampling and fitting.

5.2.7 Inclinometer Mounted on Shearer -- Stop at Various Points and Measure Roll

The last roll control concept considered has the inclinometer mounted on the shearer; however, the shearer stops, measures the roll angle commands a new roll angle of the shearer and then continues on cutting with that shearer roll angle until the next stop.

All of these roll control concepts were modeled and analyzed to determine their performance. A detailed description of the roll control simulation follows in the next section.

5.3 DESCRIPTION OF THE ROLL CONTROL SIMULATION

5.3.1 Inclinometer Sensor Model

The sensor modeled was a Moog model 86-121 inclinometer. This device uses the displacement of a sliding mass to detect inclination relative to the local vertical. The device can be viewed as a mass free to slide but subject to damping and restoring forces. When the surface on which the mass slides is tilted with respect to horizontal, gravitational acceleration moves the mass from its null position. External acceleration in the direction of motion of mass also causes motion. Given the following definitions:

x = mass displacement

m = mass

D = damping force constant

K = restoring force constant

g = acceleration due to gravity

a = disturbance accelerations

the equation of the mass motion is:

$$m\ddot{X} = - D\dot{X} - Kx + Mg \sin \phi + ma$$

The angle ϵ is the inclination of the mass relative to horizontal, and is the quantity to be sensed. Since inclination angles are small, sin ϵ may be replaced by ϵ. Figure 5-3 shows a block diagram of the solution for this equation.

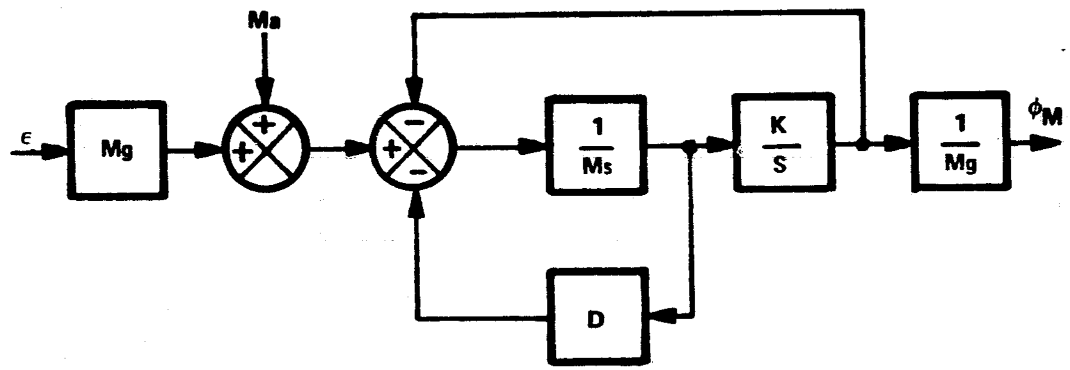


Figure 5-3. Inclinometer Model Block Diagram

The Moog sensor has a natural frequency of 2.4 Hz and a damping ratio of 0.6. The enforced version of the above equation is:

$$\ddot{X} + \frac{D}{m}\dot{X} + \frac{K}{m}X = 0$$

thus with

$$\omega_n = 2.4 \text{ Hz} = 15.08 \text{ rad/s}$$

$$\omega_n^2 = \frac{K}{m} = 227.396$$

and

$$2\zeta\omega_n = \frac{D}{m} = 18.095$$

The inclinometer equation can now be rewriten as:

$$\ddot{X} = - 18.095\dot{X} - 227.396X + 32.2\phi + a$$

As shown in Figure 5-3, the output of the sensor is the displacement divided by Mg to yield an angular equivalent, ϕ_M.

5.3.2 Vibration Environment

The inclinometer must be mounted on the shearer with its sensitive axis normal to the face, if it is the sense the desired roll angle. As a result of this orientation, the inclinometer will also sense cross-axis accelerations normal to the face resulting from the shearing drums when cutting. The precise nature of these cross-axis disturbances was not known, so a bandlimited white noise process was used to simulate this noise. The simulated noise was a zero mean

process with an exponential correlation; this is white noise through a first order linear filter. The first order filter was set to a 100 Hz bandwidth in these studies.

Throughout the results which follow, the cross-axis disturbances will be specified as RMS g levels. The square of this, the signal variance, represents the total g^2 in the 100 Hz bandwidth, or the area under the noise spectrum. The spectral level of the white noise passed through the low pass filter is found by dividing the variance by the bandwidth.

5.3.3 Actuator - Shearer Model

The hydraulic actuation of the roll system is performed by two hydraulic cylinders operated in parallel. These cylinders are 22.25 in. long when retracted, and have a cam extension of 8 in. The actuators are mounted such that a 4 in. extension gives zero roll angle relative to the skid plane. Therefore, within the range of the cam extension, a roll of ± 5 deg is possible. Figure 5-4 shows the shearer geometry. The distance from the shearer pivot to actuator is 47 in. When the actuator is at its nominal extension of 4 in., ϕ_0 = 29.2 deg. The roll of the shearer ϕ is the change in roll relative to ϕ_0. The equation for the shearer roll angle in terms of actuator displacement is given as:

$$\phi = \cos^{-1} \frac{D_1^2 + D_2^2 - (X_0 + X_a)^2}{2D_1 D_2} - \phi_0$$

This is the same relationship used in the Vertical Control System to determine ranging arm angles.

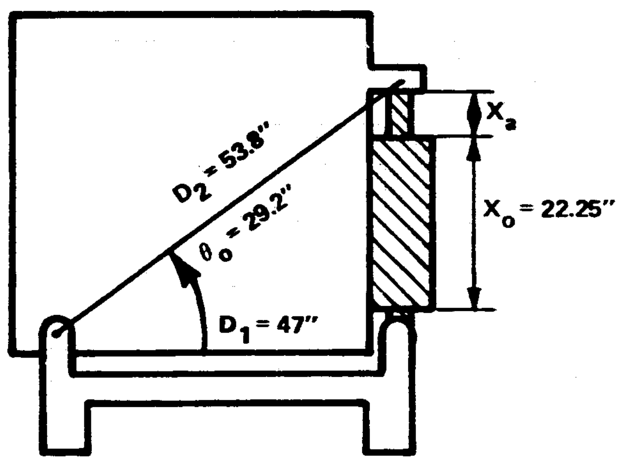


Figure 5-4. Shearer Geometry for Roll Control

The model used for the shearer-actuator system is the same as the VCS actuator system shown in Figure 3-16 in Reference 1. For this simulation, however, the lengths D and W are replaced by lengths D_1 and D_2, respectively. The simulation was also modified such that its range of roll was ± 5 deg. The model, therefore, assumes that the pair of actuators can be treated as one actuator, and that the roll system has the same dynamic response and nonlinearities as the VCS system. Finally, the second order loop simulating arm flexibility in the VCS model was not used in the roll studies. Figure 5-5 shows the roll actuator model.

5.3.4 Roll Control Concepts

Baseline System -- Inclinometer Mounted on the Shearer

Block diagrams of the two Baseline Roll Control Systems was shown previously in Figure 5.1. These systems were modeled the same as described in Reference 1. In the open loop system the inclinometer output is used as an error signal to drive the roll actuator. In the closed loop system the inclinometer output is used to compute the desired roll angle command. The open loop system gain K, was set at 2750. For the closed loop system, the gain K_2 was set at 170.

Inclinometer Mounted on Separate Cart

The block diagram of the roll control concept where the inclinometer is mounted on a separate cart is shown in Figure 5.6. The conveyor roll angle ϕ_C is the inclinometer input with the cart velocity V_C and the standard deviation of the noise σ_I as parameters. The inclinometer output ϕ_M is sampled and then straight lines are fitted between sample points. In the actual system, the resulting measured roll profile ϕ_{MS} is defined as a function of distance along the conveyor. In the simulation ϕ_{MS} is defined as a function of time since the velocity of the shearer is assumed to be constant. This profile is then used as a command to the shearer roll system on the next cut.

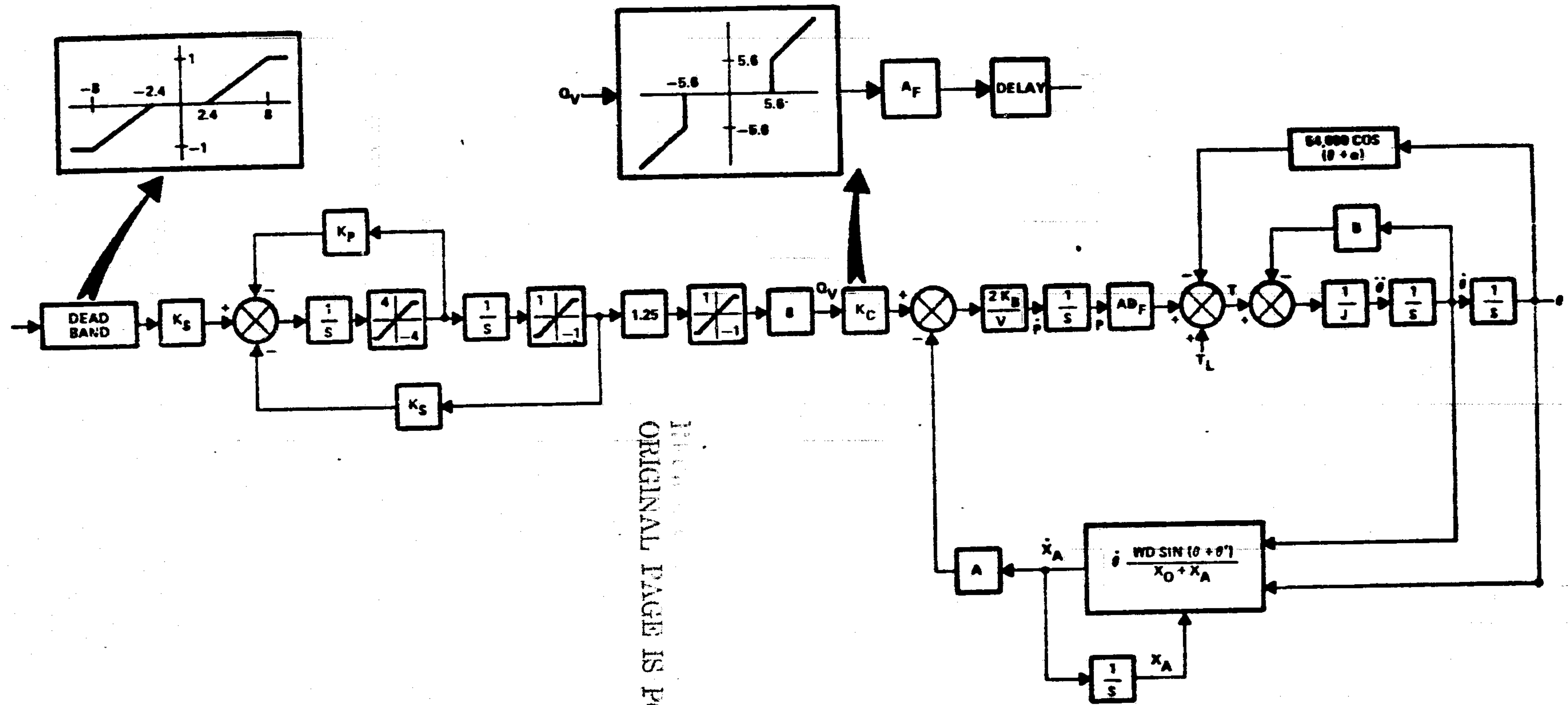


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Figure 5-5. Actuator and Ranging Arm Simulation Model

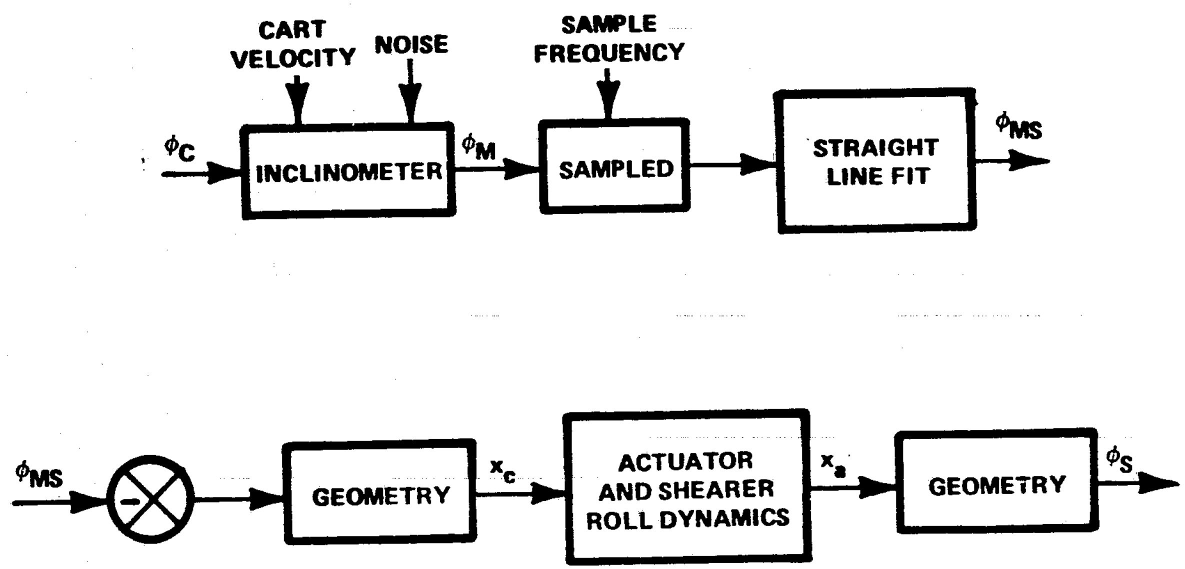

Figure 5-6. Roll Control Concept - Inclinometer Mounted on Separate Cart

Inclinometers Mounted on Conveyor Proper

The roll control concept where inclinometers are mounted on the conveyor proper is simualted as shown in Figure 5.7. The roll profile ϕ_C is sampled as a function of distance along the conveyor -- the sample points correspond to the location of the inclinometers. Since the inclinometers are located on the conveyor, no dynamic response or noise is simulated. Straight lines are fitted, as before, between the sampled points. The resulting profile ϕ_{MS} is defined as a function of time and used as a command input to the shearer roll system.

Inclinometers Mounted on the Roof Supports

The block diagram of the roll control concept that uses inclinometers mounted on the roof supports is shown in Figure 5.8. The roll profile ϕ_R of the roof supports is sampled and then a straight line is fitted between the points to obtain ϕ_{MS}. The frequency of the sampling is a parameter representing the location of the roof support inclinometers. The roof support roll profile is the same as the conveyor roll profile on the previous pass.

The fitted roll profile ϕ_{MS} is used as a command input to the shearer roll system.

Inclinometer Mounted on the Shearer -- Measure and Cut on the Clean-Up Pass

This roll control concept contains the same control loop as the baseline system. After cutting on the clean-up pass, the conveyor is advanced. The shearer is then commanded zero roll during the actual cut.

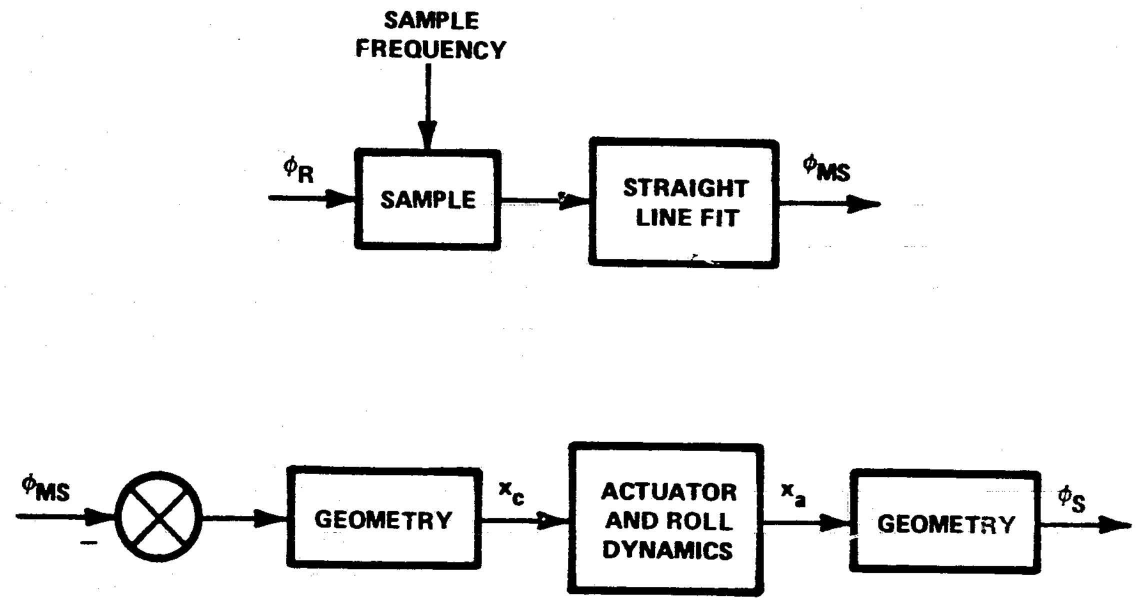

Figure 5-7. Roll Control Concept - Inclinometers Mounted on Conveyor Proper

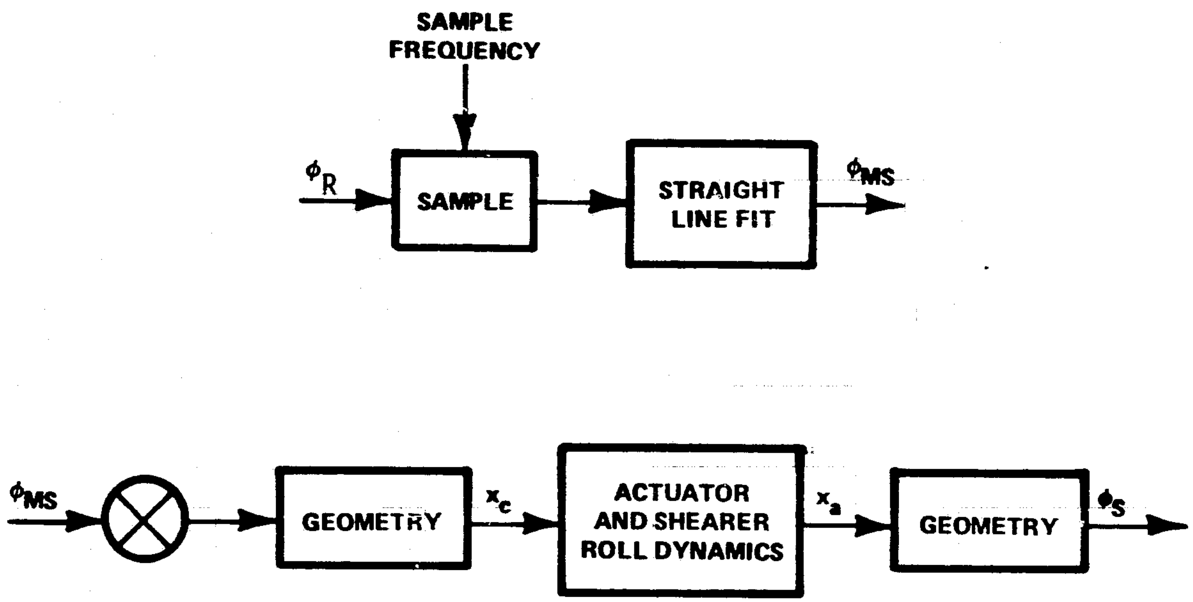

Figure 5-8. Roll Control System - Inclinometers Mounted on Roof Supports

Inclinometer Mounted on the Shearer --
Measure Without Cutting on the Clean-Up Pass

The block diagram of the roll control concept that uses an inclinometer mounted on the shearer and measures without cutting on the clean-up pass is shown in Figure 5.9. On the clean-up pass the shearer roll angle ϕ_S is set to zero so that the inclinometer input is the roll profile ϕ_C. The inclinometer output ϕ_M is added to the shearer roll profile ϕ_S, recorded when the shearer cut coal on the previous pass. The sum is then sampled and straight lines fitted between the points to obtain ϕ_{MS}. It is assumed that the conveyer is then advanced and the roll profile ϕ_{MS} is the command input to the shearer roll system.

Inclinometer Mounted on the Shearer --
Stop and Measure Roll

Figure 5.10 shows the block diagram of the roll control concept that has a shearer mounted inclinometer and that stops the shearer at various points to measure roll. The inclinometer output is sampled, held, and used as a command input to the shearer roll system until the shearer stops again. Since the shearer stops before measuring the inclinometer dynamics are negligible. The inclinometer is, therefore, not modeled. The frequency at which the shearer stops is a system parameter.

5.3.5 Conveyor Roll Model

The conveyor roll angle is simulated as shown in Figure 5-11. The shearer roll angle ϕ_S is summed with the conveyor roll angle ϕ_C to obtain the roll of the cutting drums. Noise ϵ_C is then added and this signal is filtered to obtain the new conveyor roll profile for the next advance. The noise is introduced to simulate random variations in the roll profile resulting when the conveyor is advanced. Three different filters are simulated to model conveyors of different flexability. They are defined as follows:

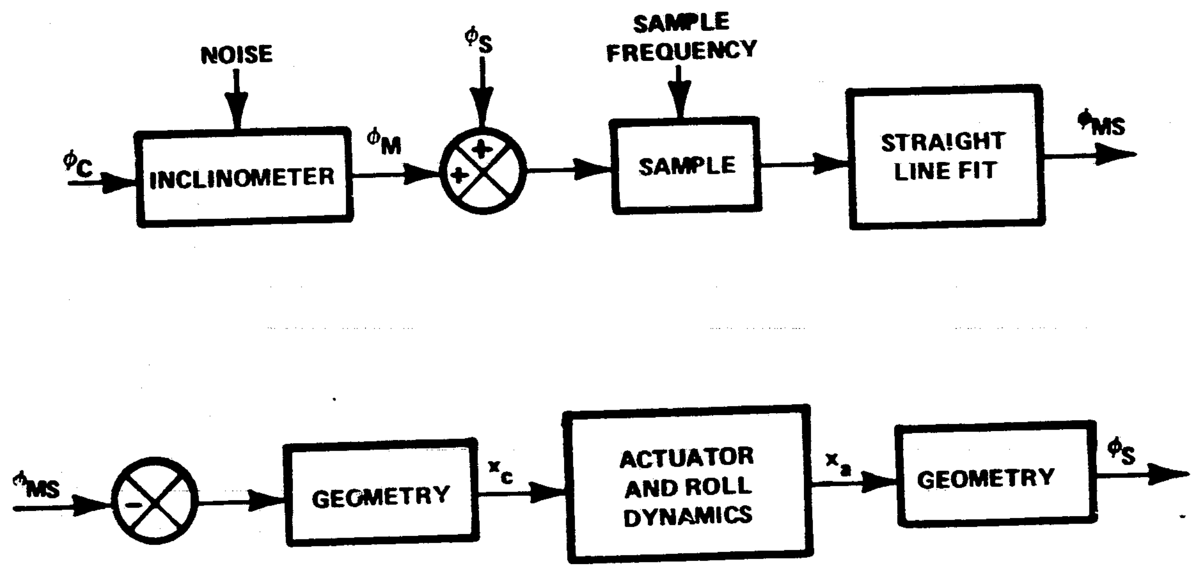

Figure 5-9. Roll Control System - Inclinometers Mounted on Shearer, Measure Without Cutting on the Clean-Up Pass

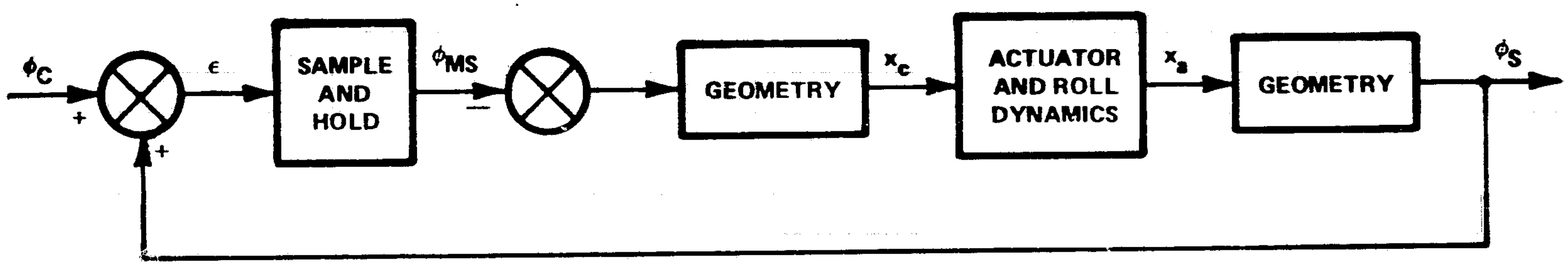

Figure 5-10. Roll Control System - Inclinometer Mounted on the Shearer, Stop and Measure Roll

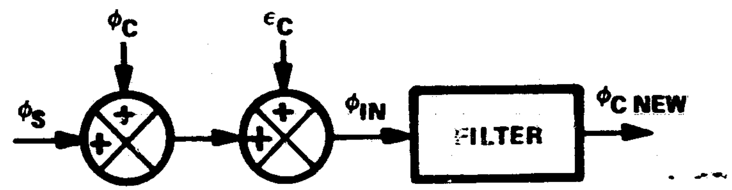

Figure 5-11. Simulation Model of Conveyor Roll Profile

0.05 HZ Filter

$$\phi_{CNEW} = \frac{1}{26.1S^3 + 13.9S^2 + 5.6S + 1} \phi_{in}$$

0.025 HZ Filter

$$\phi_{CNEW} = \frac{1}{209.52S^3 + 55.49S^2 + 11.22S + 1} \phi_{in}$$

0.0125 HZ Filter

$$\phi_{CNEW} = \frac{1}{1676.13S^3 + 221.96S^2 + 22.45S + 1} \phi_{in}$$

Figures 5-12 through 5-14 show an example of the conveyor roll profile for each filter obtained after a single advance with ϕ_S and ϕ_C equal to zero.

5.4 ROLL CONTROL SYSTEM PERFORMANCE

The roll control system performance was determined by running the roll simulation for ten advances of the conveyor. On each advance, 126 seconds of solution was obtained; this is equivalent to the shearer traveling 63 ft along the conveyor at a velocity of 30 ft/min. On the first cut the conveyor is assumed to be level.

The critera for performance for each run is the RMS of the roll error ($\phi_S + \phi_C$). If the RMS increases with each advance, the system, of course, is unstable.

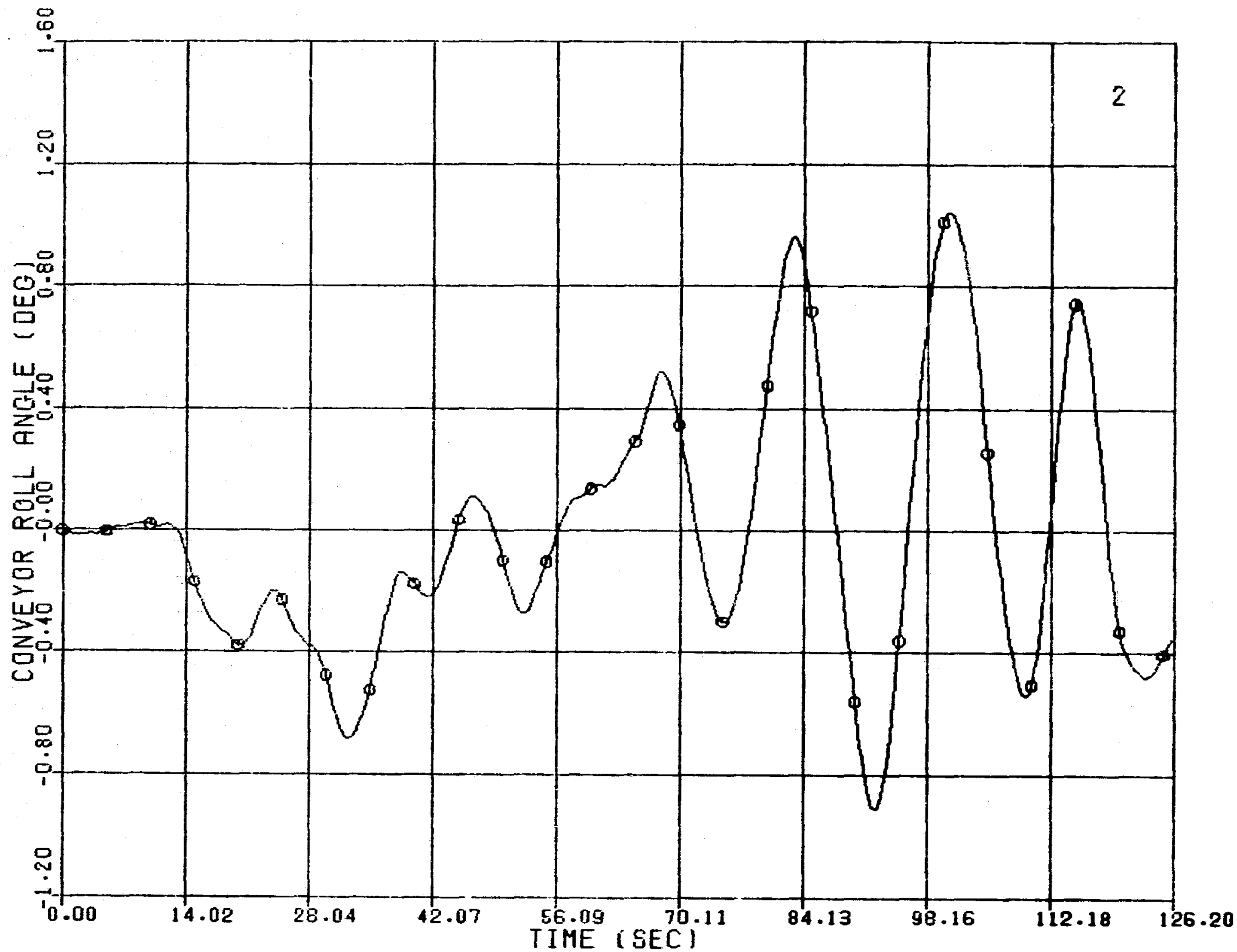

Figure 5-12. Example of Conveyor Roll Profile Simulated with 0.05 Hz Filter

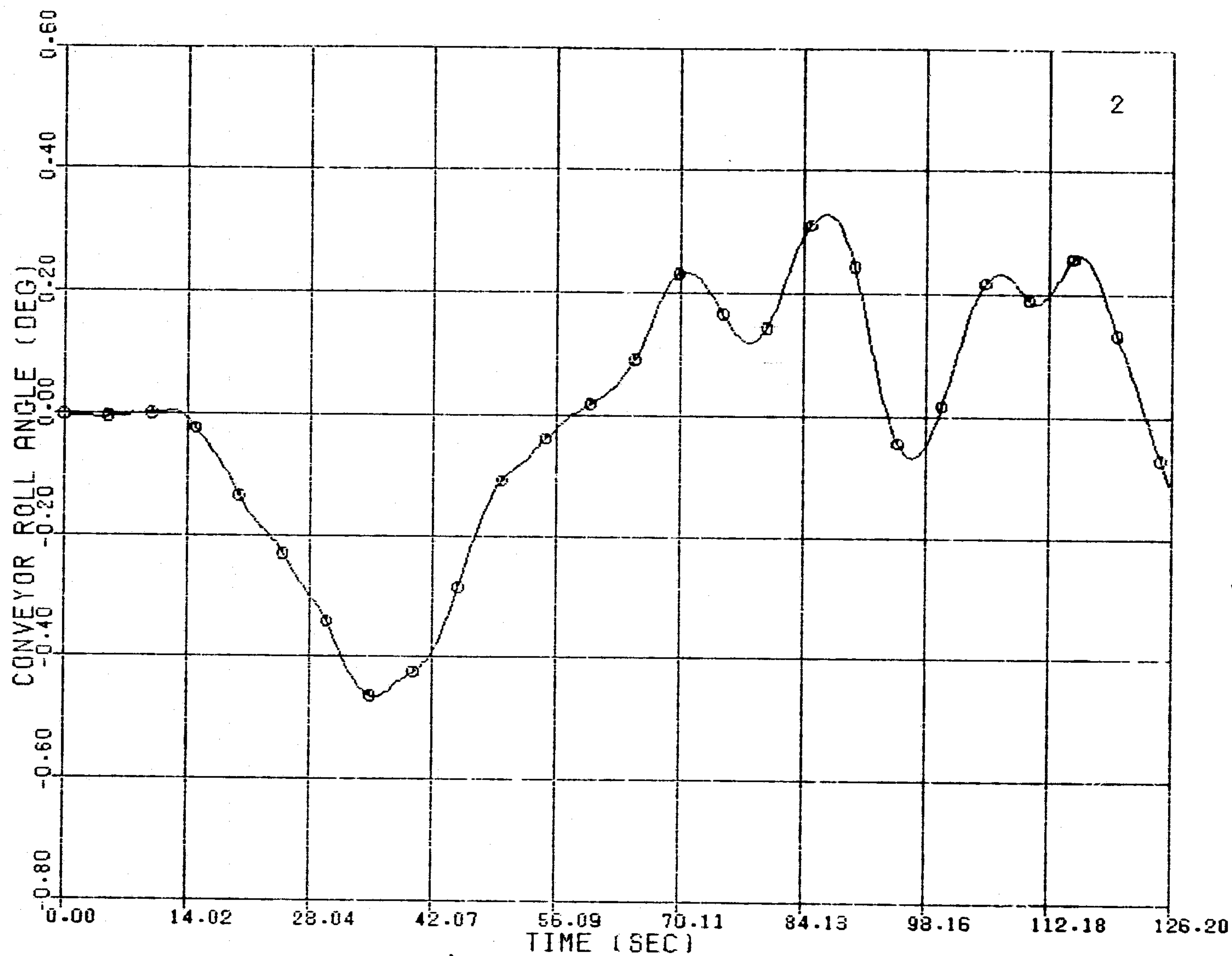

Figure 5-13. Example of Conveyor Roll Profile Simulated with a 0.025 Hz Filter

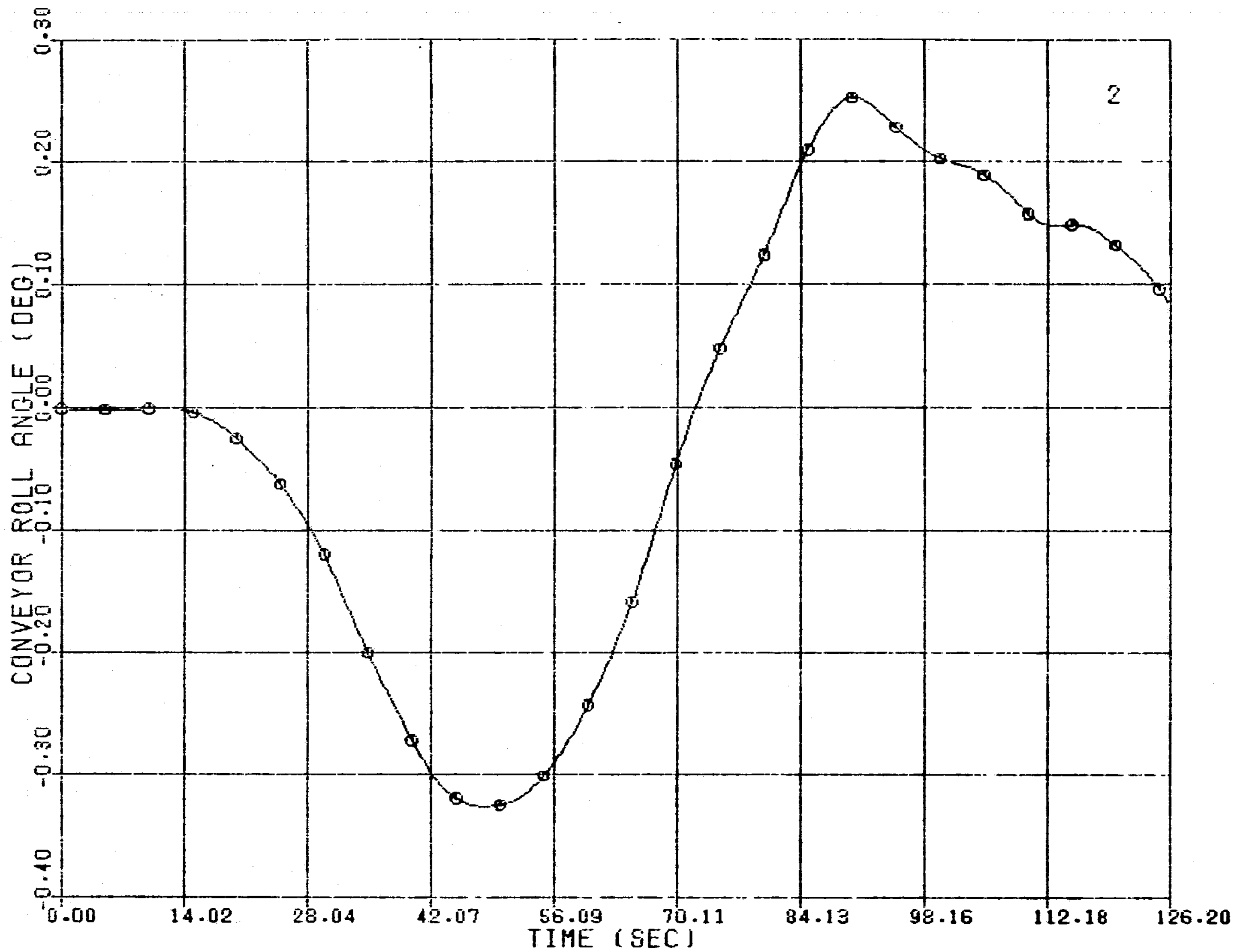

Figure 5-14. Example of Conveyor Roll Profile Simulated with a 0.0125 Hz Filter

5.4.1 Baseline Roll System Performance

The baseline roll control system has the inclinometer mounted on the shearer. Both a closed loop and an open loop system are considered. The closed loop system uses the inclinometer output to compute the desired shearer roll command. Results of the simulation for ten advances of the conveyor are shown in Figure 5-15. In this figure the conveyor filter was 0.05 Hz and three standard deviations of inclinometer noise were considered. It can be seen that the roll error RMS varies with each advance. For zero inclinometer noise the mean RMS error for the ten advances is 0.44 degrees. The standard deviation of these ten RMS values is σ_{RMS} = 0.07 degrees. Table 5-1 lists the mean and standard deviation of the RMS roll errors for all three conveyor filters and for three cross axis acceleration values. The results show that the RMS roll error does not continue to grow with each advance. Also, if the conveyor is as flexable as that represented by the 0.05 Hz filter, then inclinometer noise is high as 0.5 g's will cause roll angle variations near the geometric limits of the conveyor.

Time histories of the closed loop system performance are shown in Figures 5-16 through 5-24. These figures show the actuator displacement, the shearer and conveyor roll angle, and the roll error for the first three advances. The conveyor roll filter was 0.05 Hz and the inclinometer noise was 0.2 g's.

The performance of the open loop system was also studied. The results are shown in Table 5-2. This table compares the open and closed loop system performances using the 0.025 Hz conveyor filter. It can be seen that there is little difference between the two systems.

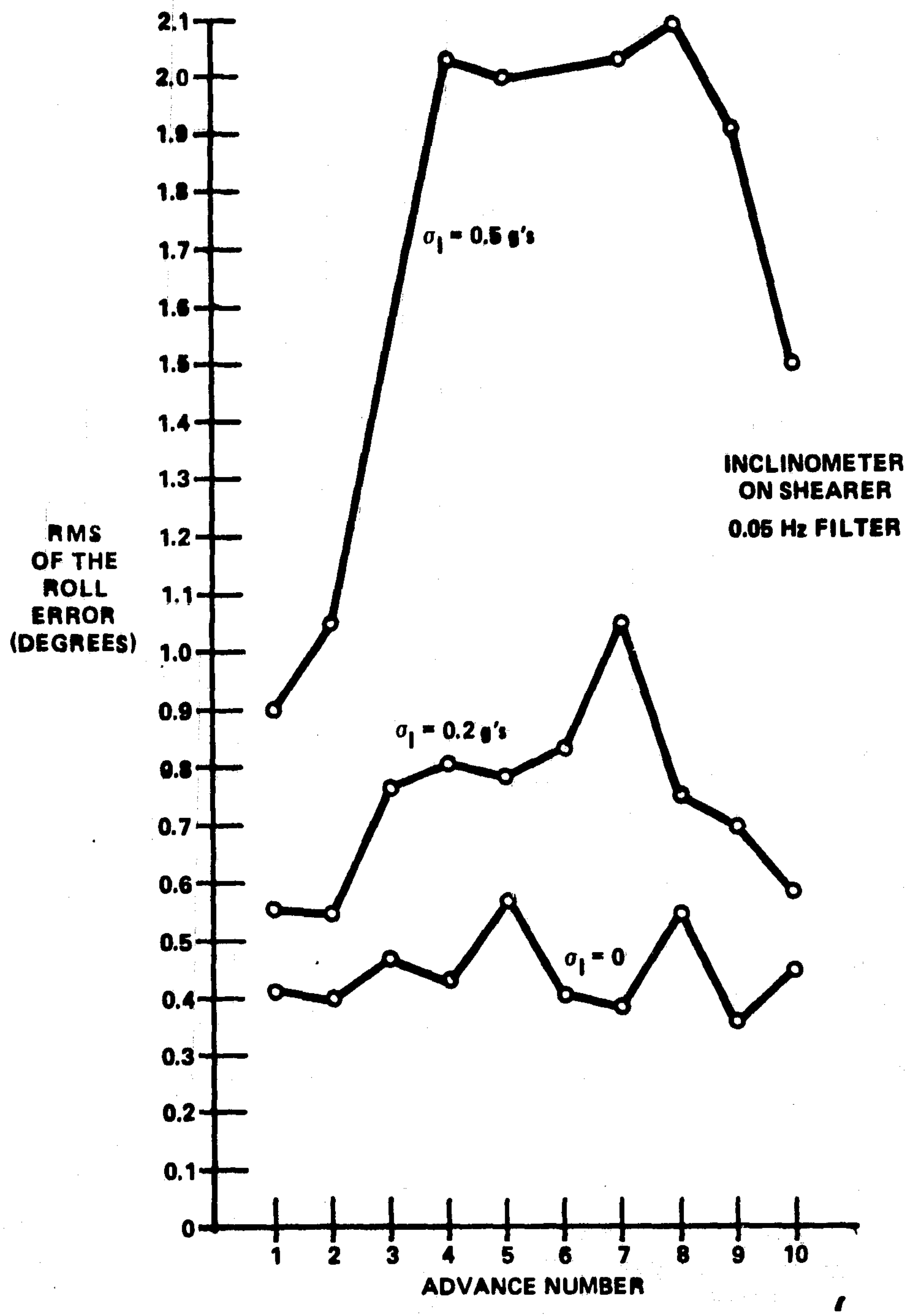

Figure 5-15. Simulation Results of the Baseline Roll Control System - Closed Loop

Table 5-1. Performance of Closed Loop Baseline Roll Control System

Cross Axis Acceleration	σ_I	0		0.2 g's		0.5 g's	
RMS Roll Error (degrees)		Mean	σ_{RMS}	Mean	σ_{RMS}	Mean	σ_{RMS}
Conveyor Filter HZ	0.0125	0.21	0.06	0.38	0.15	0.73	0.26
	0.025	0.31	0.08	0.58	0.17	1.07	0.28
	0.05	0.44	0.07	0.74	0.15	1.71	0.44

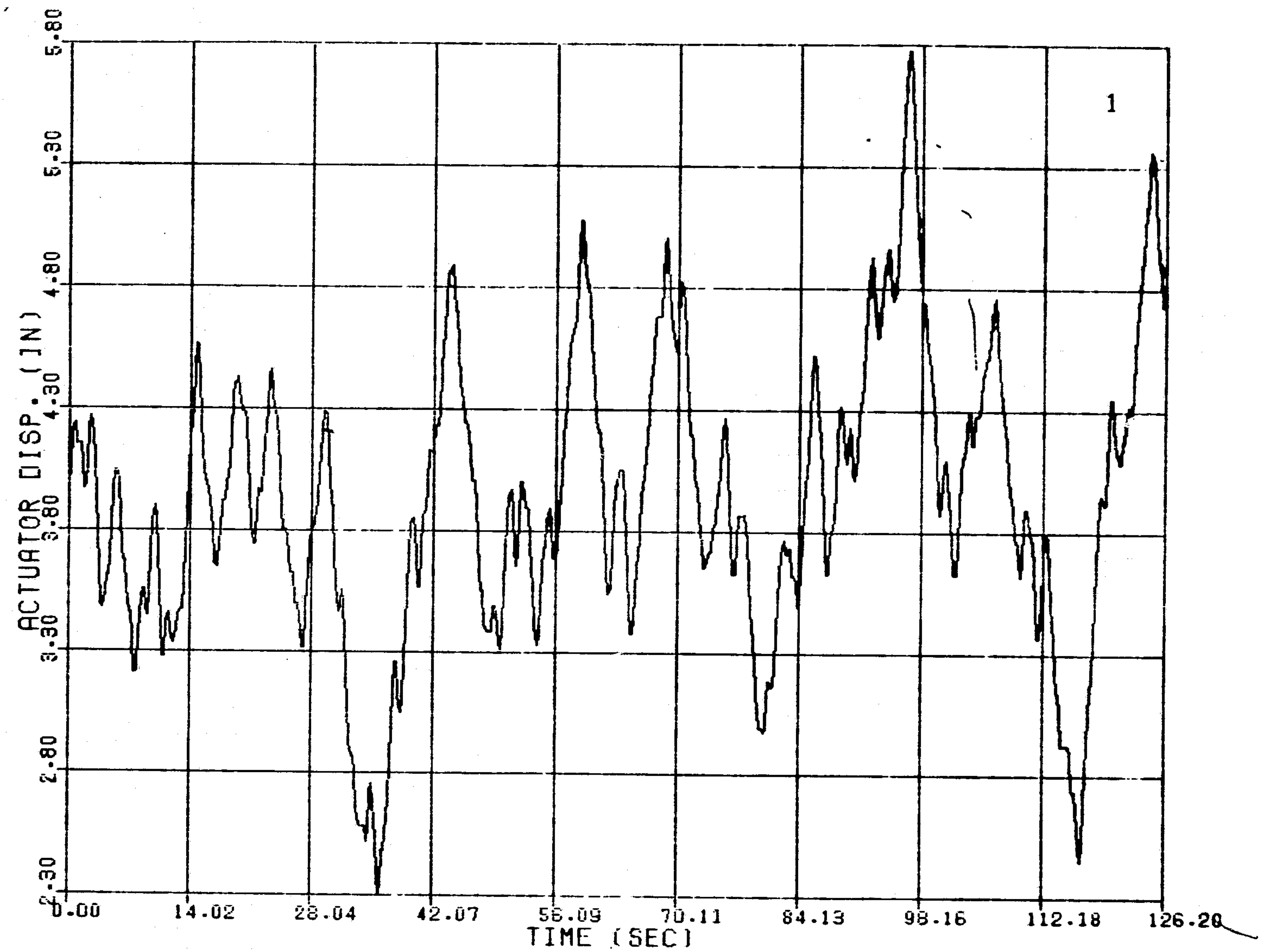

Figure 5-16. Time History of Baseline Roll Control System - Actuator Displacement, Advance Number 1

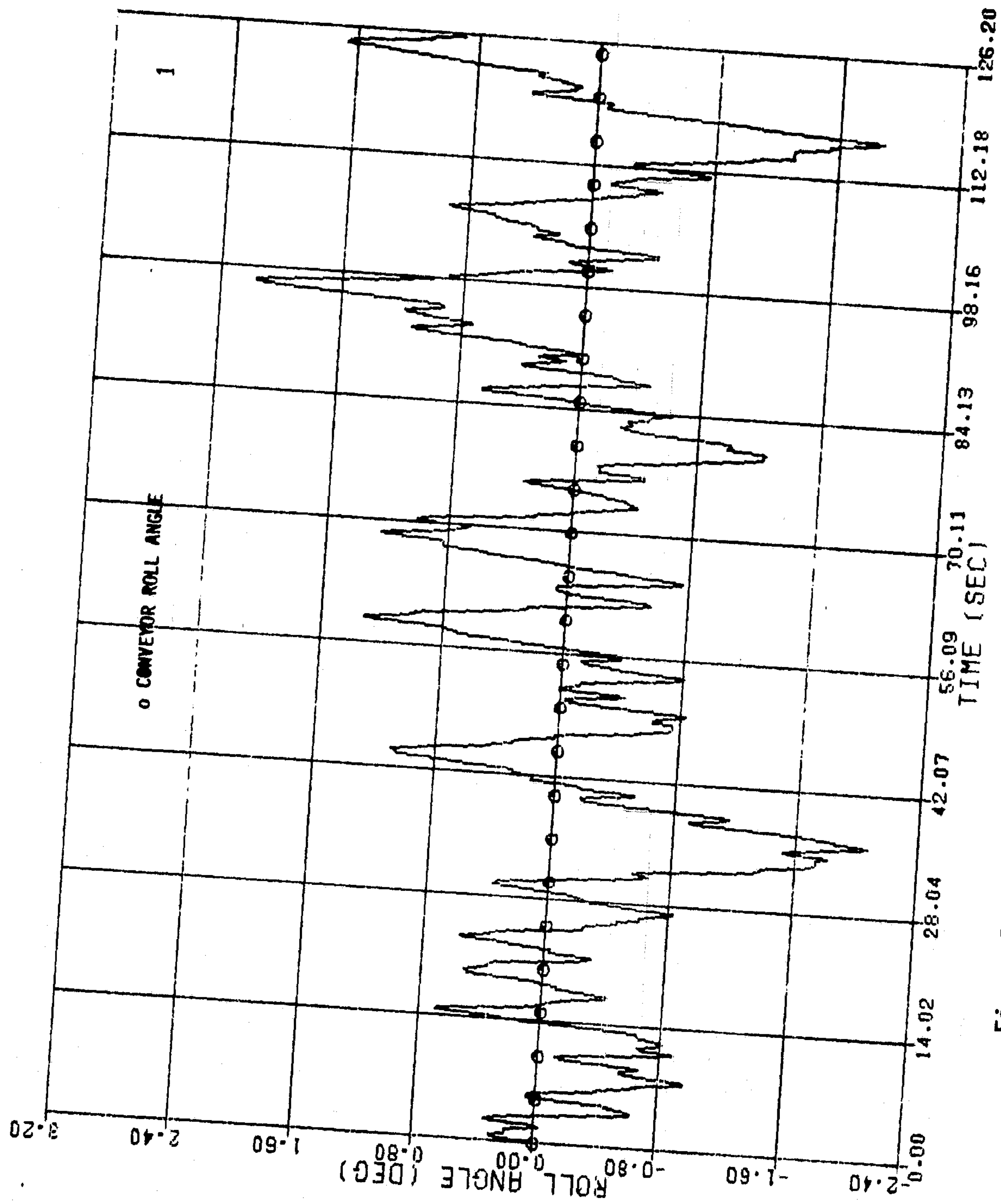

Figure 5-17. Time History of Baseline Roll Control System - Shearer Roll Angle, Advance Number 1

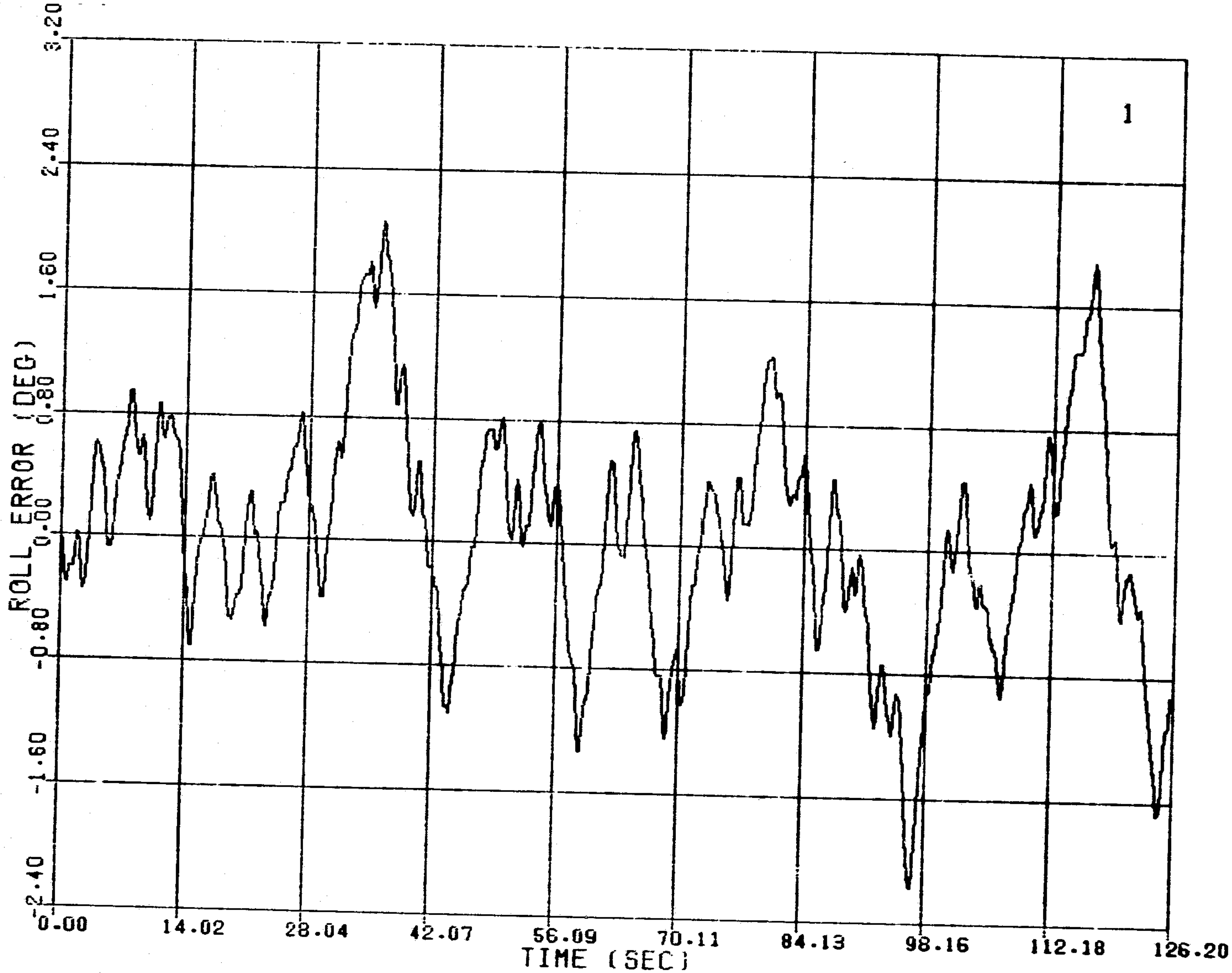

Figure 5-18. Time History of Baseline Roll Control System - Roll Error, Advance Number 1

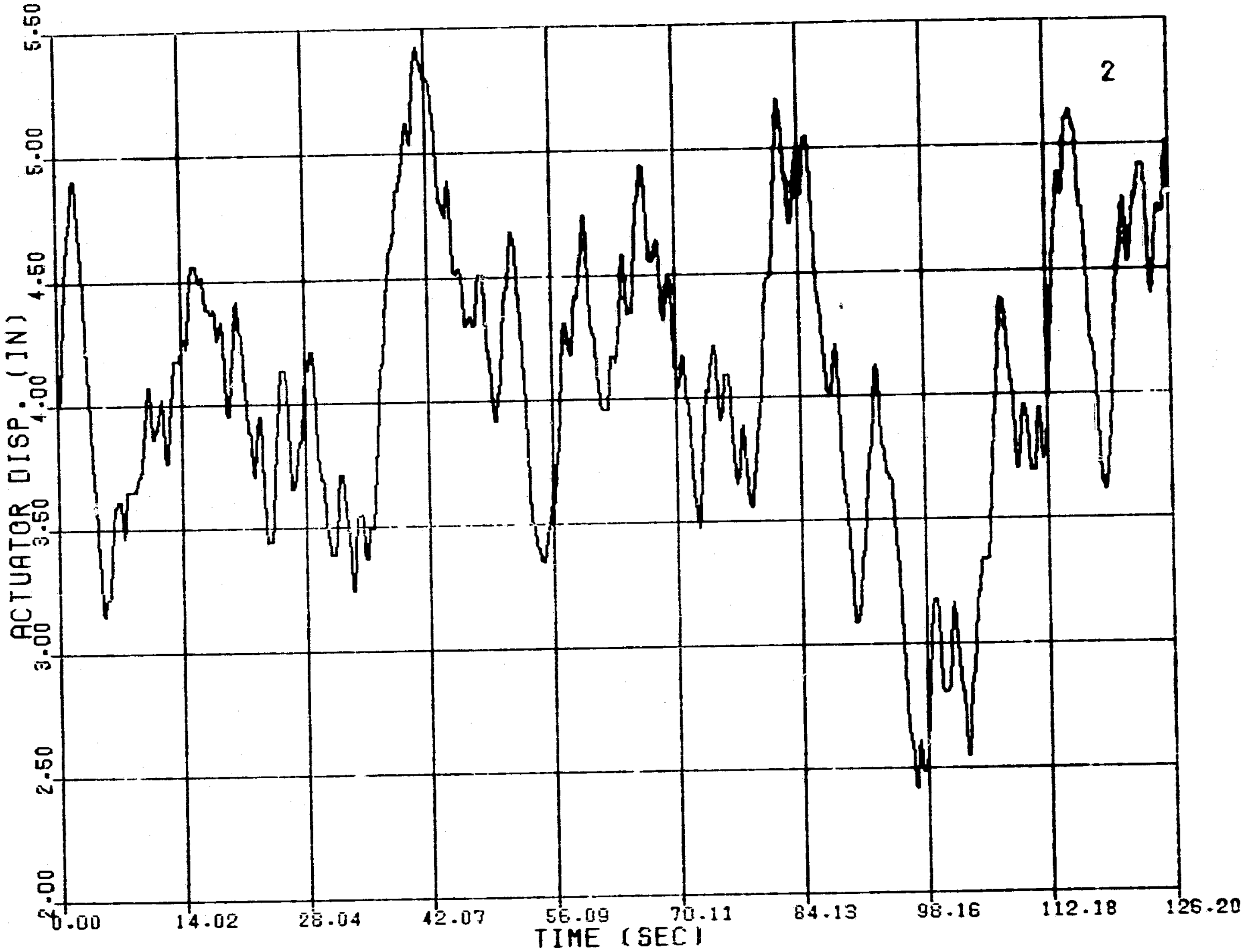

Figure 5-19. Time History of Baseline Roll Control System - Actuator Displacement, Advance Number 2

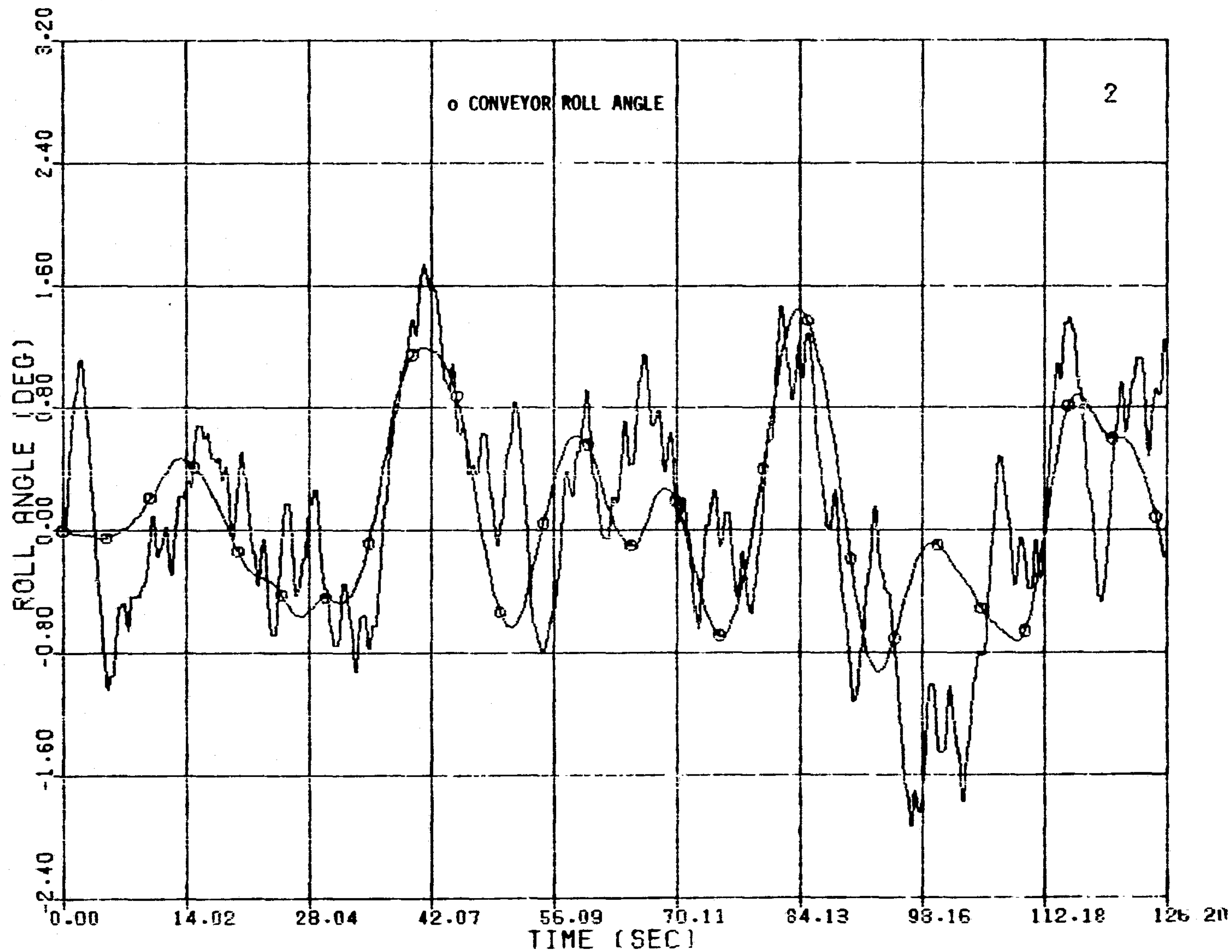

Figure 5-20. Time History of Baseline Roll Control System - Shearer Roll Angle, Advance Number 2

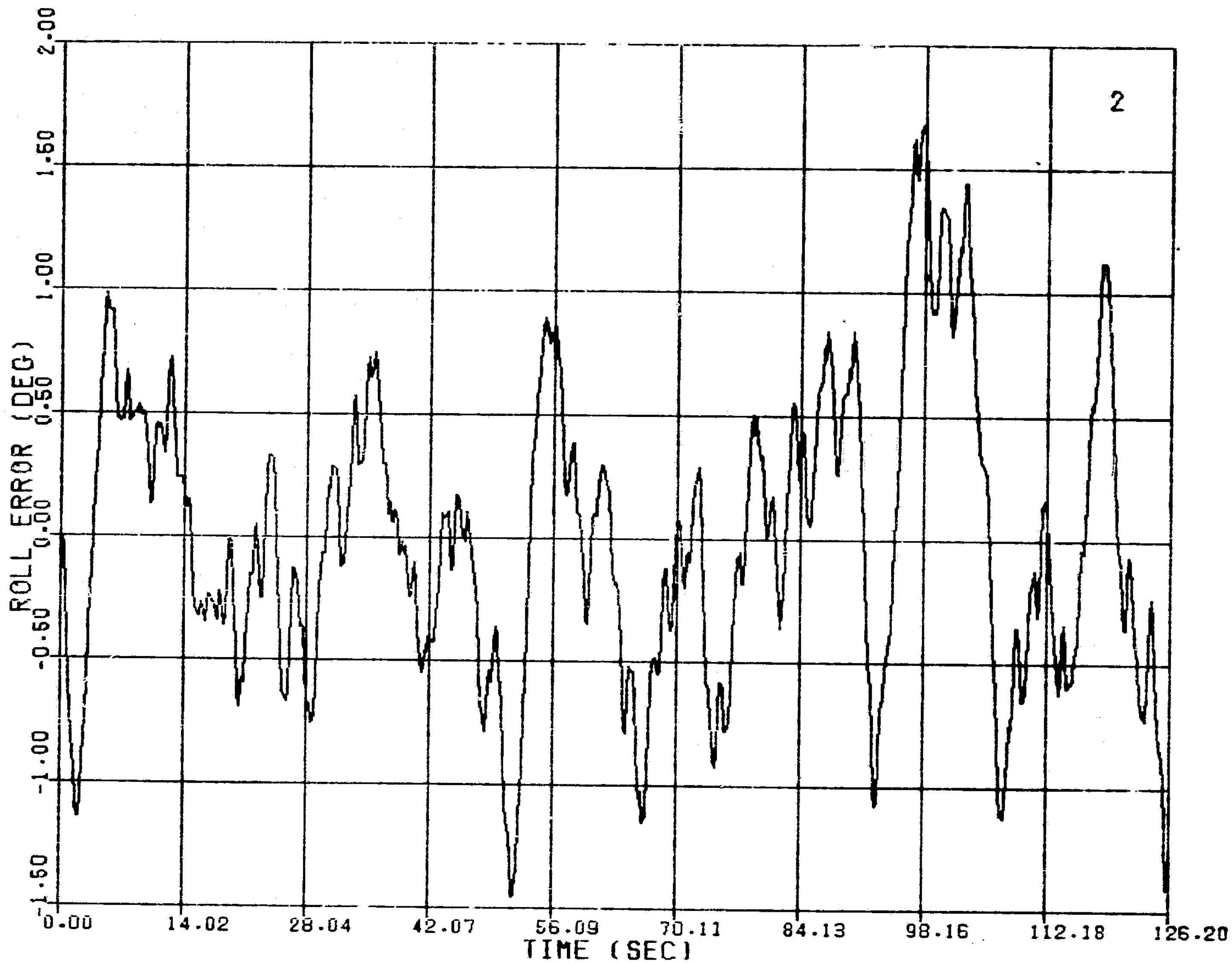

Figure 5-21. Time History of Baseline Roll Control System - Roll Error, Advance Number 2

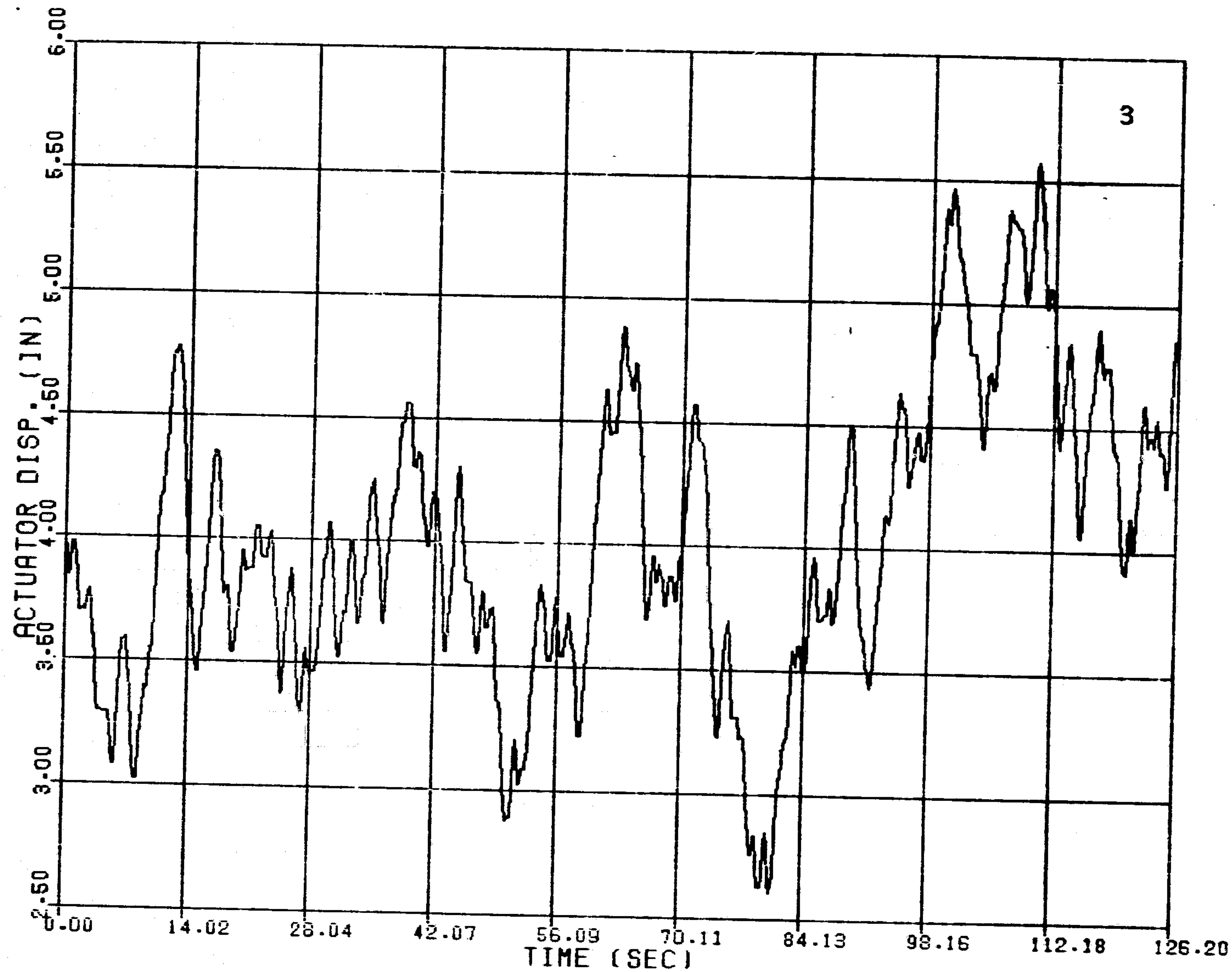

Figure 5-22. Time History of Baseline Roll Control System - Actuator Displacement, Advance Number 3

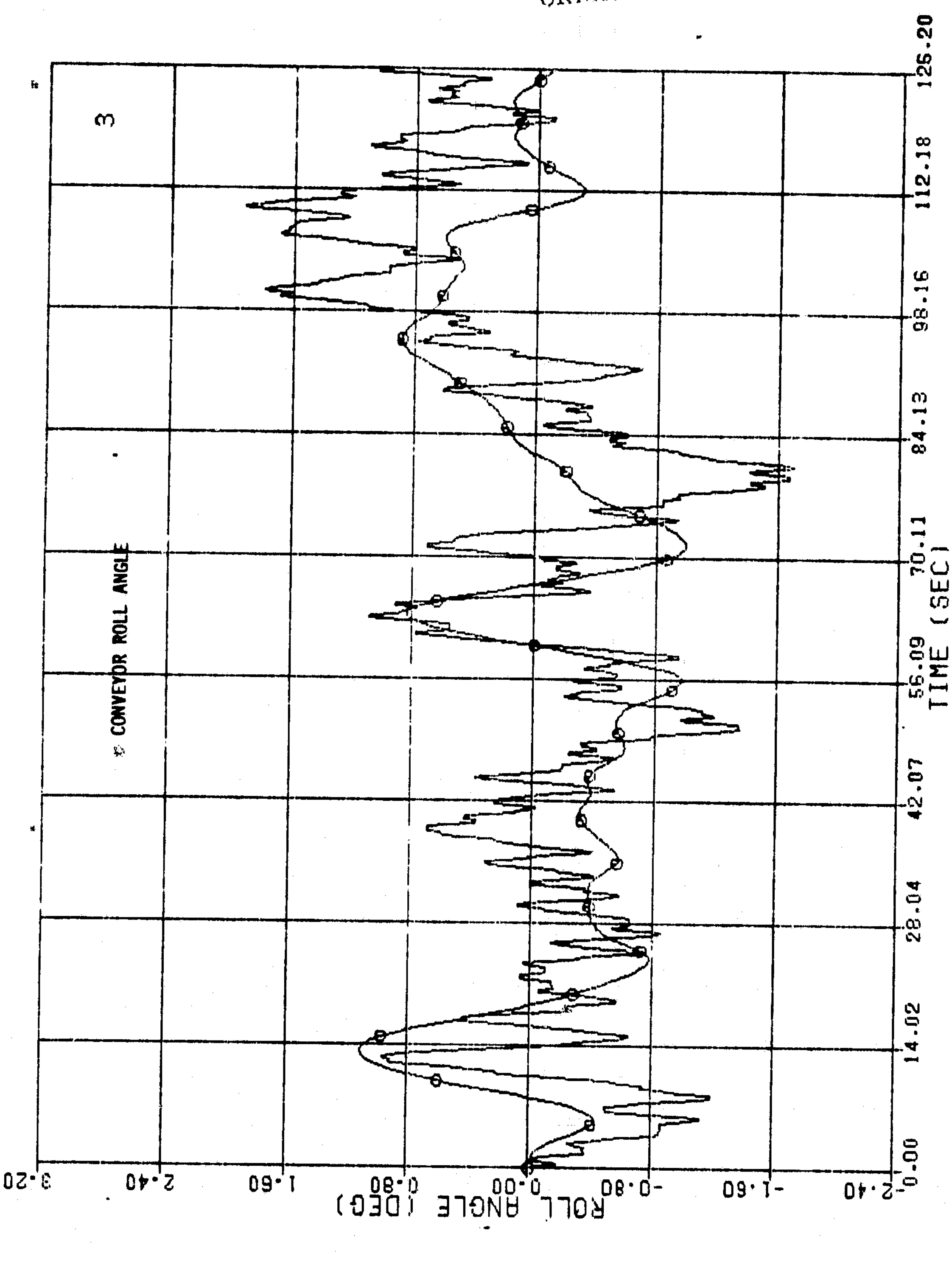

Figure 5-23. Time History of Baseline Roll Control System - Shearer Roll Angle, Advance Number 3

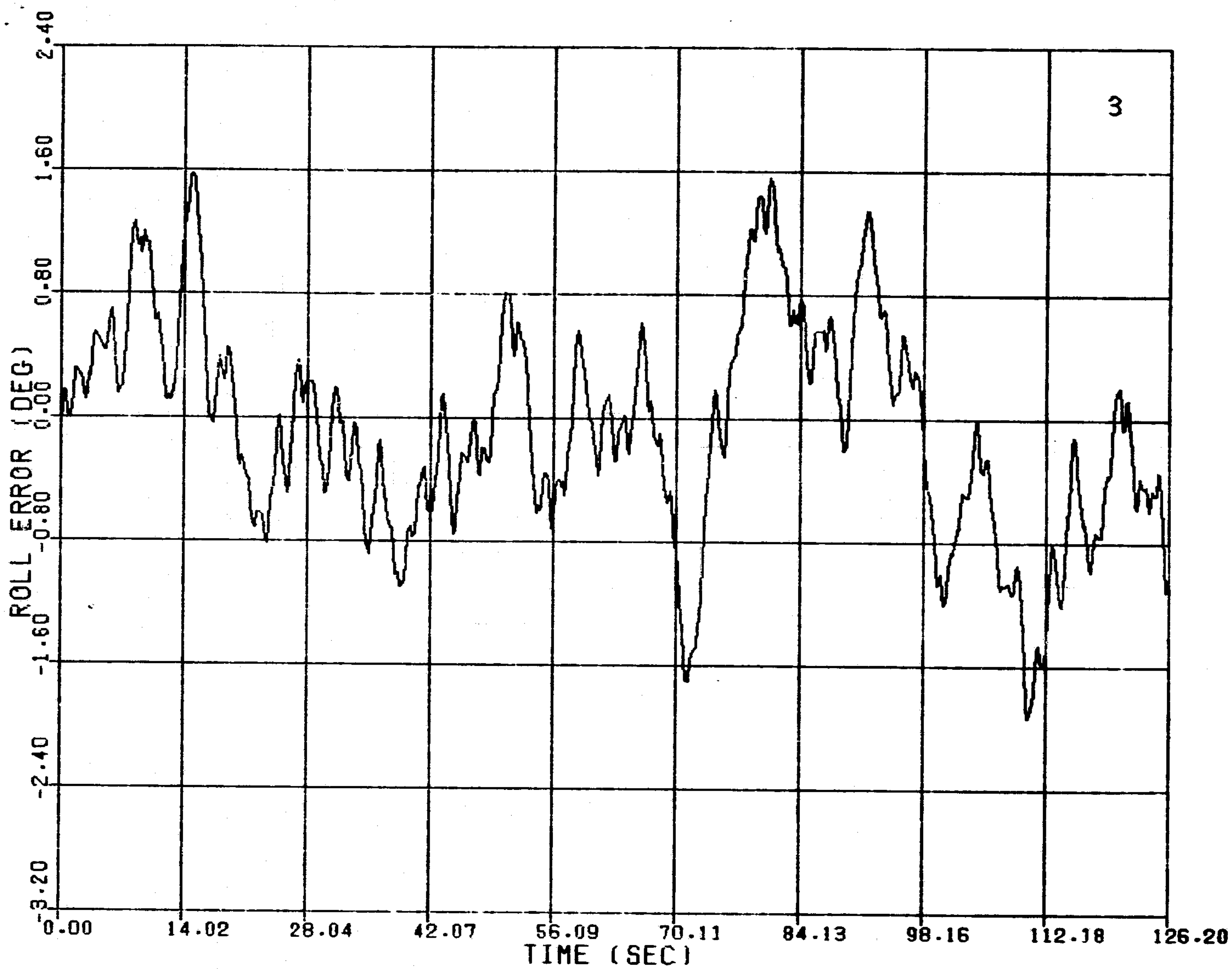

Figure 5-24. Time History of Baseline Roll Control System - Roll Error, Advance Number 3

Table 5-2. Comparison of the Open and Closed Loop Baseline System Performances - Conveyor Filter - 0.025 Hz

Cross Axis Acceleration	0		0.2 g		0.5 g's	
RMS Roll Error (degrees)	Mean	σ_{RMS}	Mean	σ_{RMS}	Mean	σ_{RMS}
Closed Loop	0.31	0.08	0.58	0.17	1.07	0.28
Open Loop	0.32	0.08	0.57	0.17	1.08	0.29

5.4.2 Alternate Roll Control Concept Performances

One of the alternate roll control concepts studied has an inclinometer mounted on a separate cart. After the shearer has made a cut and the conveyor has advanced, the cart makes a run down the conveyor measuring the roll profile. The measurements are sampled and then a straight line is fitted between the points. This measured profile is then used as a roll command to the shearer during the next cut. In the simulation ten advances were made and for each advance the RMS of the roll error was determined. The parameters studied were cart velocity, sample interval, inclinometer noise, and conveyor filter. The results are shown in Table 5-3 where the mean and the standard deviation of the RMS roll error are listed. It can be seen that 0.1 g's of inclinometer noise has only a small affect on the system. If the sample interval is as large as 2.5 feet, system performance is degraded considerably. Increasing the cart velocity from a 30 ft/min to 240 ft/min has little effect on system performance. A conveyor that is as stiff as that represented by the 0.0125 Hz filter will improve performance by a factor of two. A typical set of time histories for one advance of the conveyor is shown in Figures 5-25 through 5-27.

The performance of the roll control concept that utilizes inclinometers mounted on the conveyor proper is depicted in Figure 5-28. This figure shows that if the inclinometers located on the conveyor are spaced more than 5 feet apart then the roll error will increase with each advance. Time histories of system variables for a typical advance with the inclinometers spaced at 5 foot intervals are shown in Figures 5-29 through 5-31.

As determined with the simulation model, the roll control concept that utilizes inclinometers mounted on the roof supports is unstable. The simulation run of five advances of the conveyor showed that the roll error increased steadly from 1.69 degrees RMS on the first advance to

Table 5-3. Performance of the Roll Control Concept Using an Inclinometer Mounted on a Separate Cart

Cart Velocity	Sample Interval	Inclinometer Noise	Conveyor Filter	RMS Roll Error (degrees)	
(ft/min)	feet	g's	Hz	mean	RMS
30	0	0	0.05	0.47	0.09
30	0	.1	0.05	0.61	0.11
30	2.5	.1	0.05	1.44	0.28
30	5.0	.1	0.05	1.70	0.38
120	5.0	.1	0.05	1.70	0.27
240	5.0	.1	0.05	1.62	0.18
30	5.0	.1	.025	1.37	0.35
30	5.0	.1	.0125	0.94	1.37

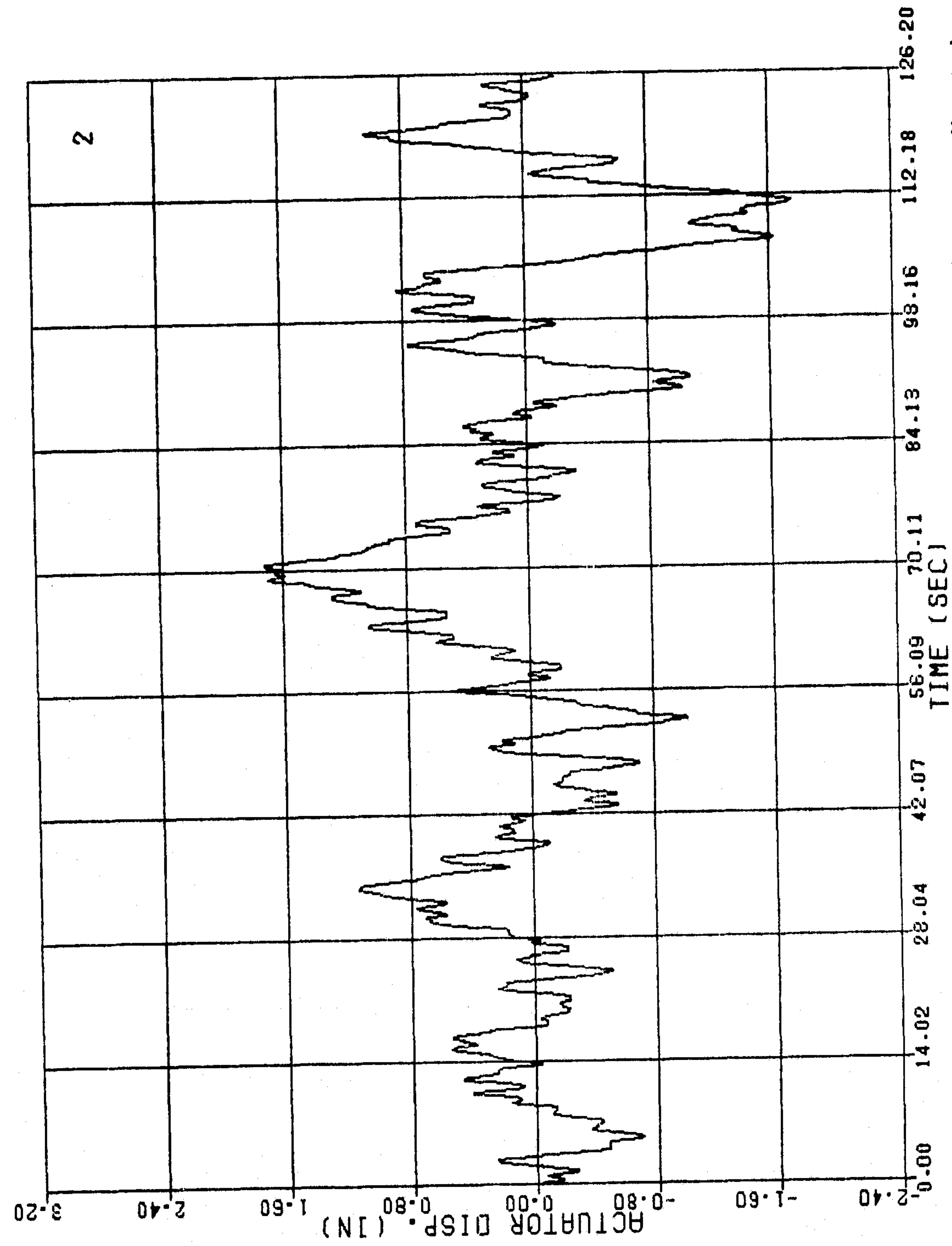

Figure 5-25. Typical Time History of Roll Control System with Inclinometer Mounted on a Separate Cart - Cart Velocity = 30 ft/min, Sample Interval = 0, Cross Axis Acceleration - 0.1 g, Conveyor Filter = 0.05 Hz

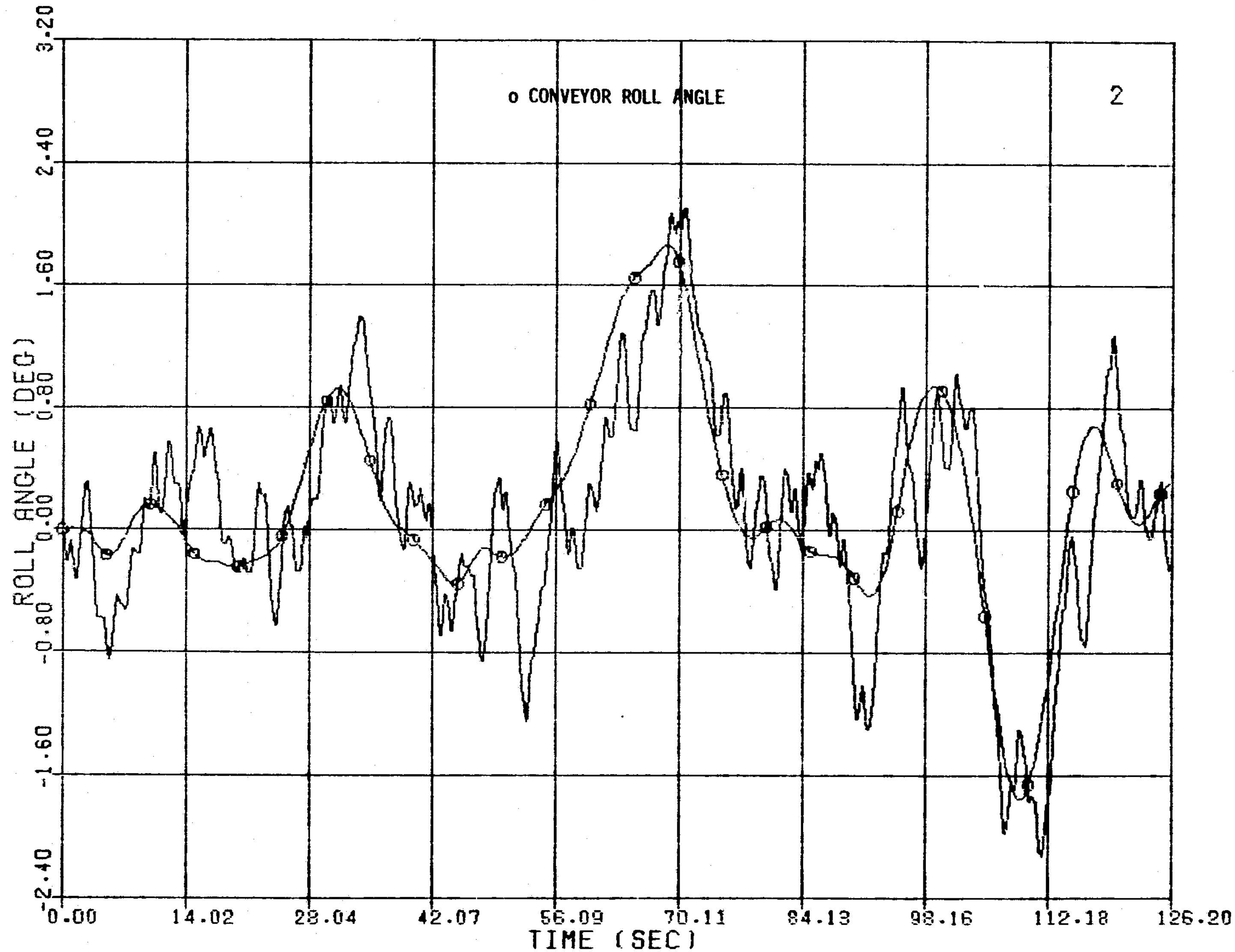

Figure 5-26. Typical Time History of Roll Control System with Inclinometer Mounted on a Separate Cart - Cart Velocity = 30 ft/min, Sample Interval = 0; Cross Axis Acceleration = 0.1 g's, Conveyor Filter = 0.05 Hz

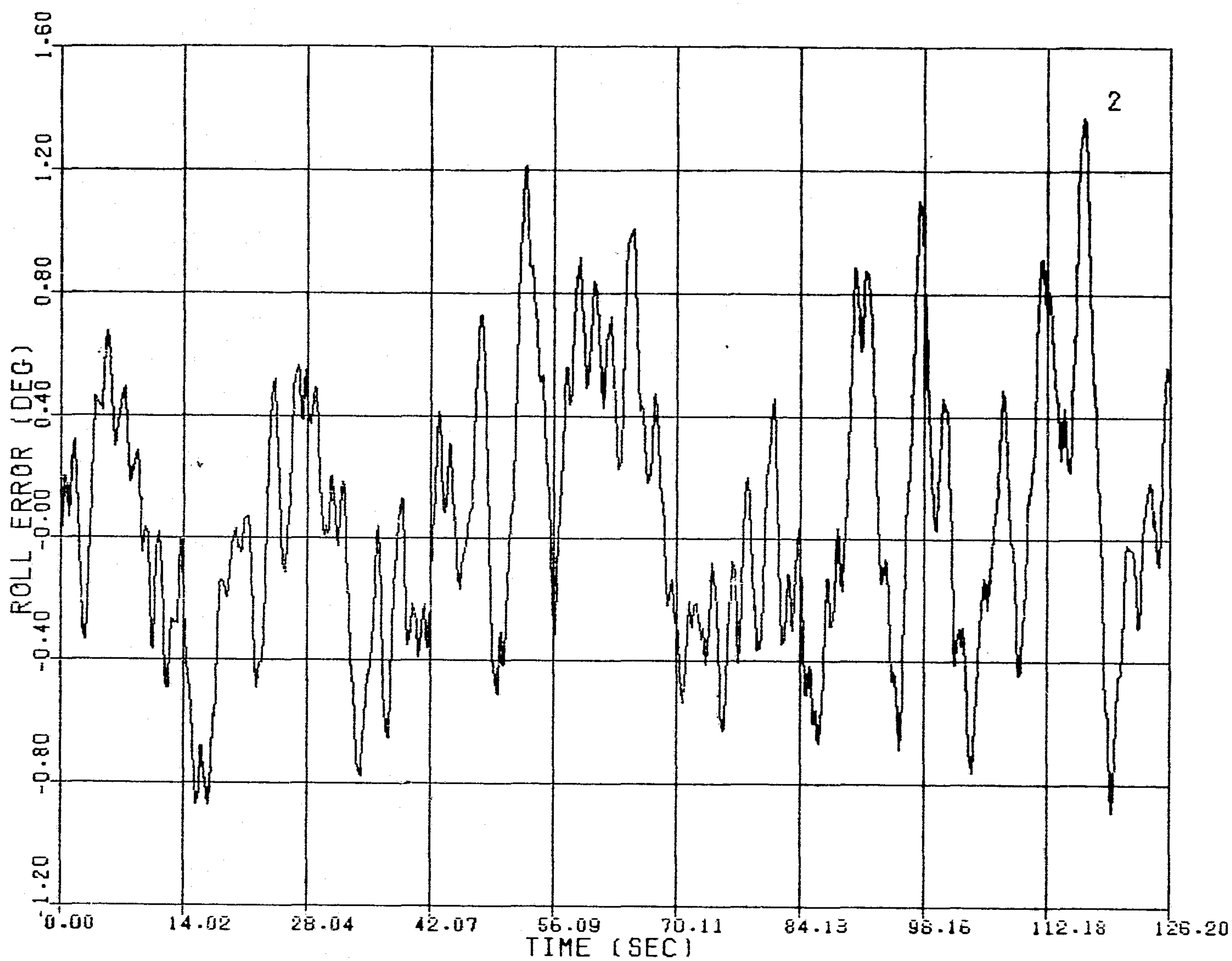

Figure 5-27. Typical Time History of Roll Control Simulation with Inclinometer Mounted on a Separate Cart - Cart Velocity = 30 ft/min, Sample Interval = 0, Cross Axis Acceleration = 0.1 g's, Conveyor Filter = 0.05 Hz

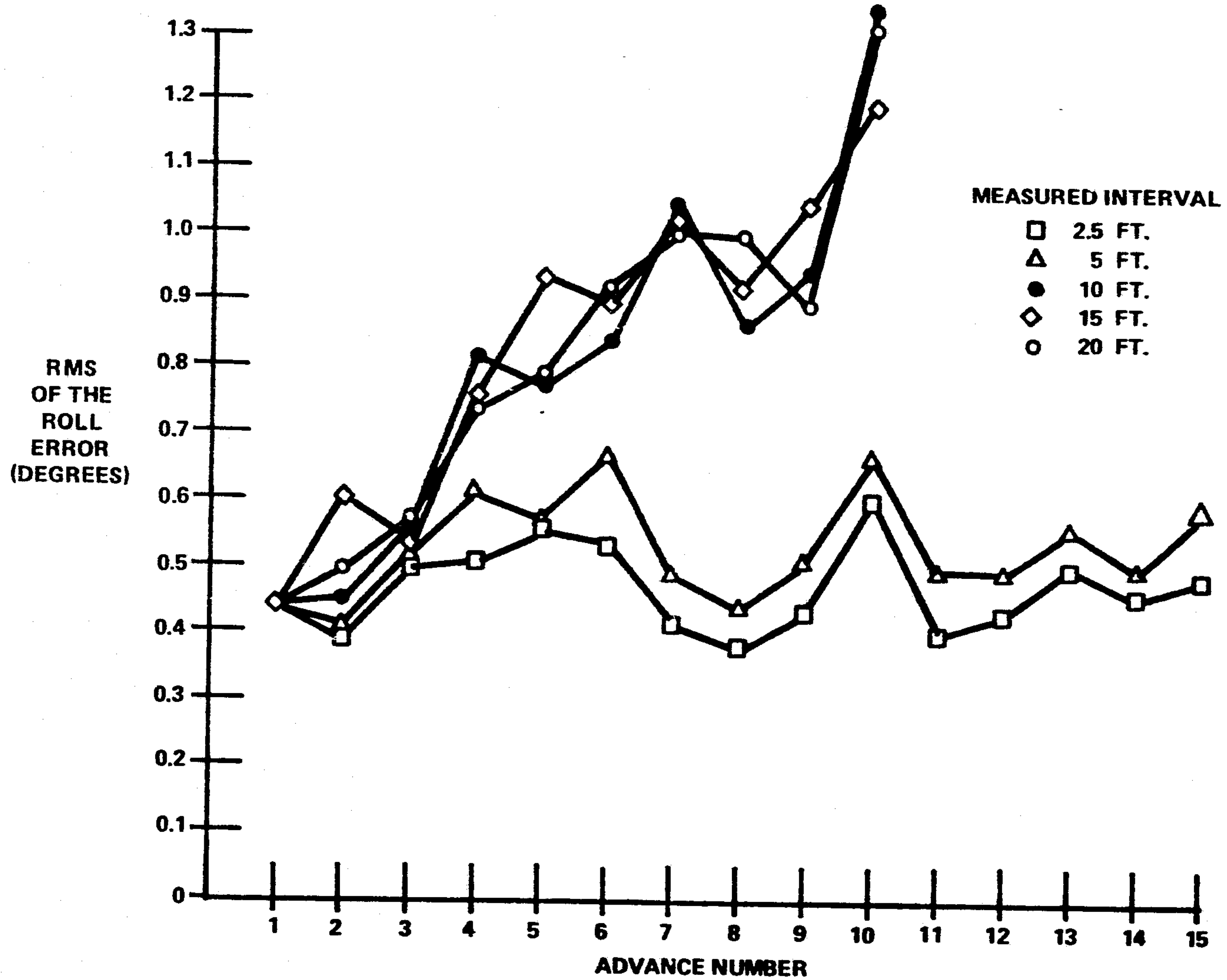

Figure 5-28. Performance of Roll Control System with Inclinometers Mounted on the Conveyor Proper

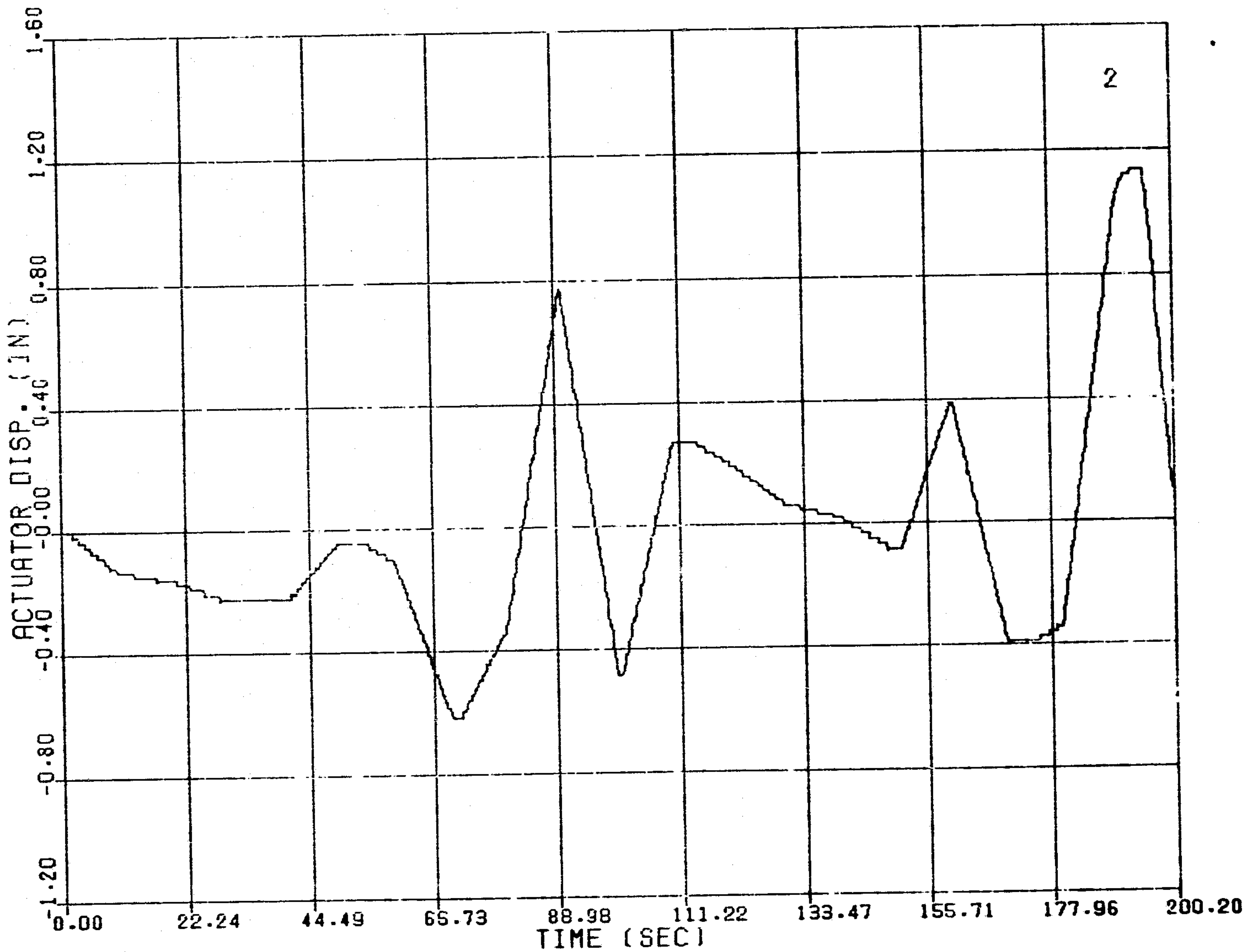

Figure 5-29. Typical Time History of Roll Control System with Inclinometer Mounted on the Conveyor Proper - Inclinometer Interval - 5 ft.

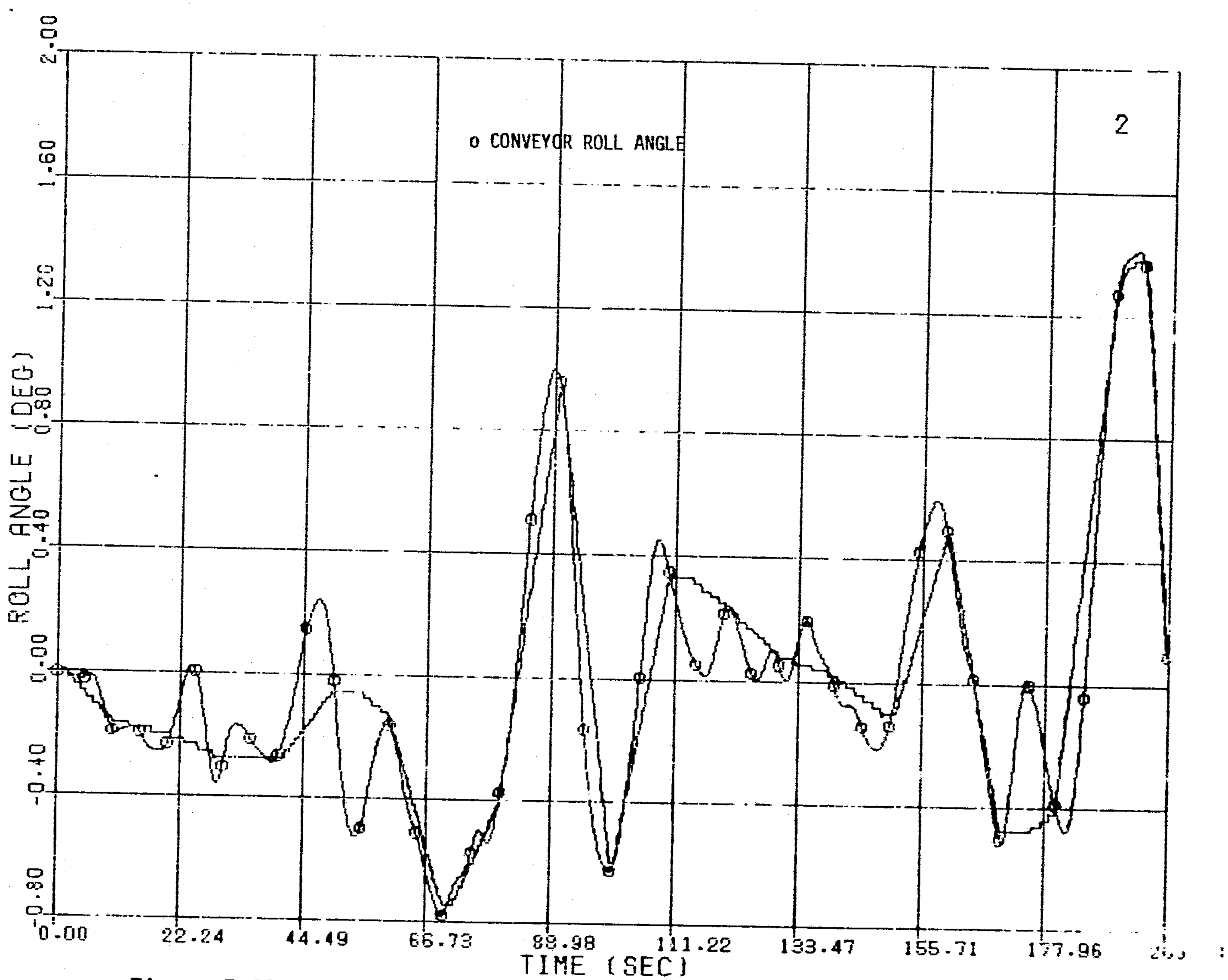

Figure 5-30. Typical Time History of Roll Control System with Inclinometer Mounted on the Conveyor Proper - Inclinometer Interval = 5 ft.

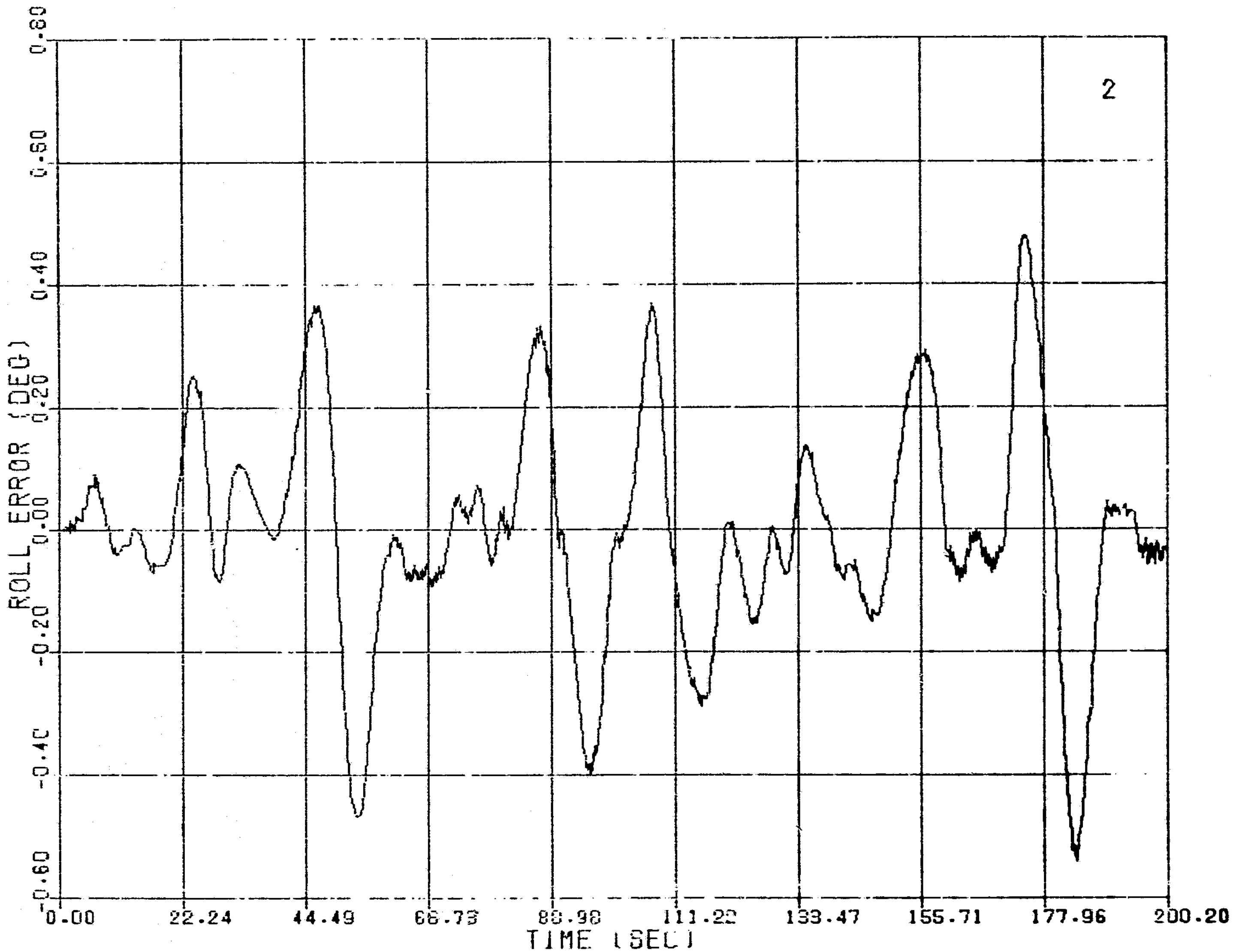

Figure 5-31. Typical Time History of Roll Control System with Inclinometer Mounted on the Conveyor Proper - Inclinometer Interval = 5 ft.

3.15 degrees RMS on the fifth advance. The inclinometers measure the roll angle one advance out of phase. As a result, the roll commands increase in amplitude with each advance.

The roll control system that utilizes an inclinometer mounted on the shearer--measuring without cutting on the cleanup pass was also studied. The roll profile of the conveyor is measured on the cleanup pass and the shearer roll angle is added to obtain the estimated roll of the cut. This sum is used as a shearer roll command after the conveyor is then advanced. The performance results of this system are shown in Figure 5-32. The RMS roll error for 10 advances of the conveyor show that the system is stable and adequately tolerant to cross axis accelerations. Table 5-4 shows the mean and the standard deviation of the RMS roll error computed from the ten advances. Also shown are the mean and standard deviation computed for a cross axis acceleration of 0.1g and a sample interval of 5 feet. The results show that a 5 foot sampling interval can easily be tolerated.

The final roll control concept studied was one with the inclinometer mounted on the shearer. Roll measurements are made when the shearer stops at regular intervals along the conveyor. The roll command to the shearer is computed from the inclinometer measurements and held constant until the shearer stops again and another measurement is taken. Simulation results for this concept are shown in Figures 5-33 and 5-34. Figure 5-33 shows the RMS roll error for a simulated 0.05 Hz conveyor filter. Stopping and measuring every 10 feet is definitely unstable. A 5 foot measurement interval is a borderline stability case. With a 0.025 Hz. conveyor filter, as shown in Figure 5-34, a stopping interval of ten feet can be tolerated. Simulation results also show that a 20 foot stop and measure interval can be tolerated with a less flexable conveyor as modeled by a 0.0125 Hz filter.

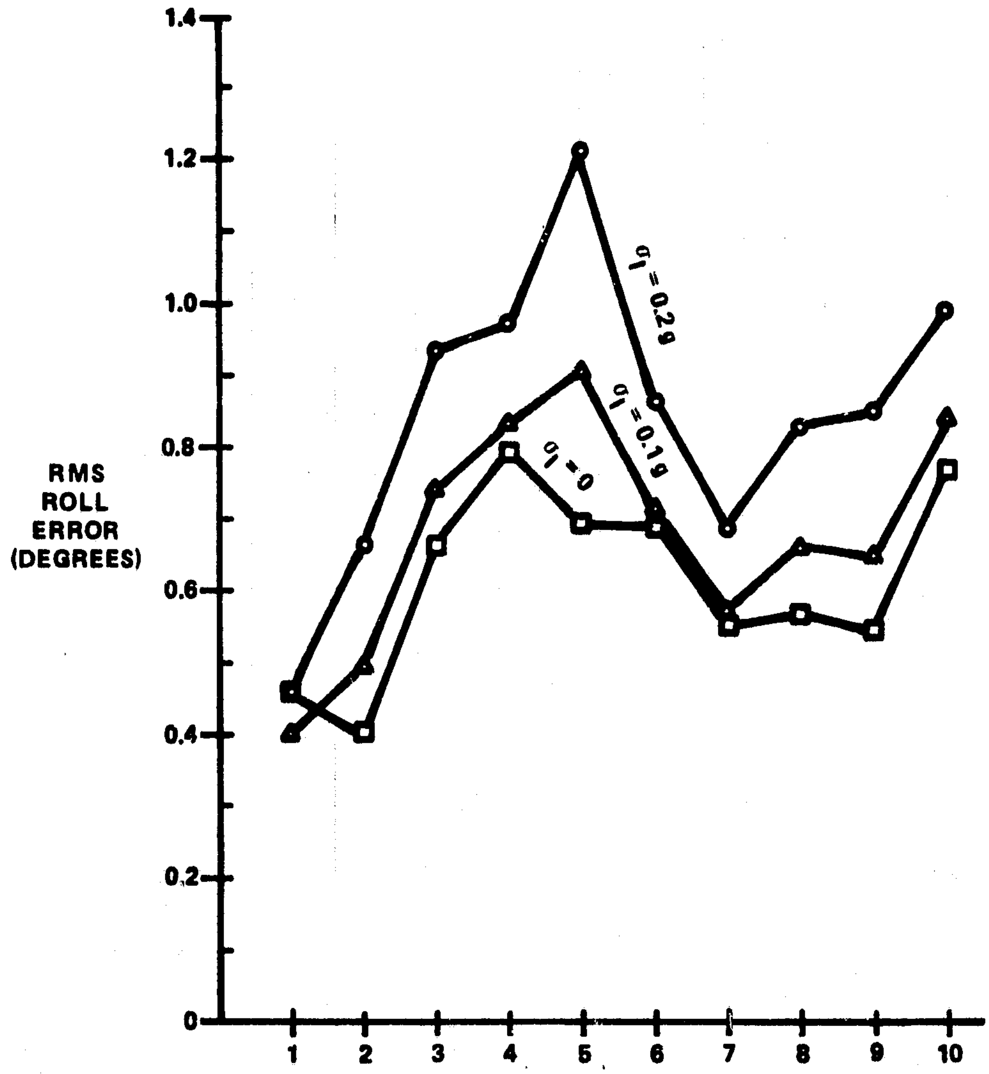

Figure 5-32. Performance Results of Roll Control System with Inclinometer Mounted on the Shearer - Stop and Measure Roll - Conveyor Filter = 0.05 Hz

Table 5-4. Performance Results of Roll Control System Using an Inclinometer Mounted on the Shearer and Measuring without Cutting on the Clean-Up Pass

Cross Axis Acceleration σ_I		0		0.1 g's		0.2 g's	
RMS Roll Error (degrees)		Mean	σ_{RMS}	Mean	σ_{RMS}	Mean	σ_{RMS}
Sample Interval	0	0.61	0.13	0.68	0.16	0.85	0.21
	5 ft	-	-	0.67	0.16	-	-

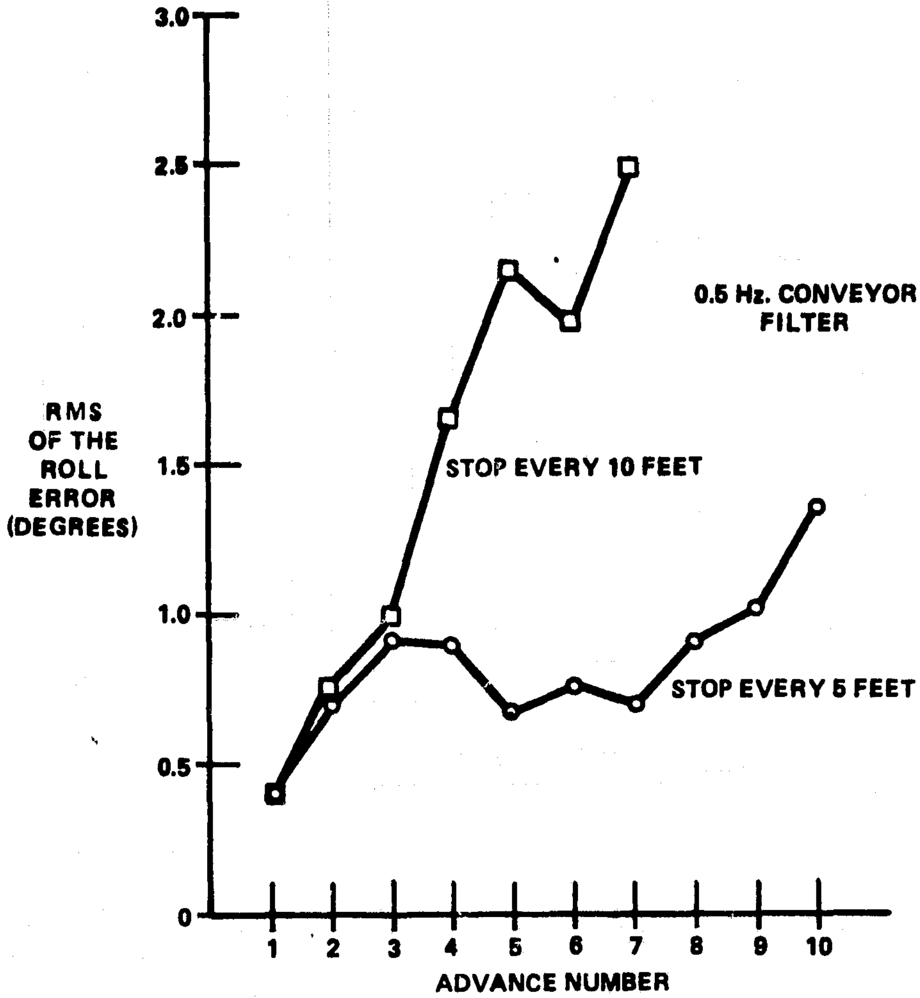

Figure 5-33. Performance Results of the Roll Control System with an Inclinometer Mounted on the Shearer - Stop and Measure, Conveyor Filter = 0.025 Hz

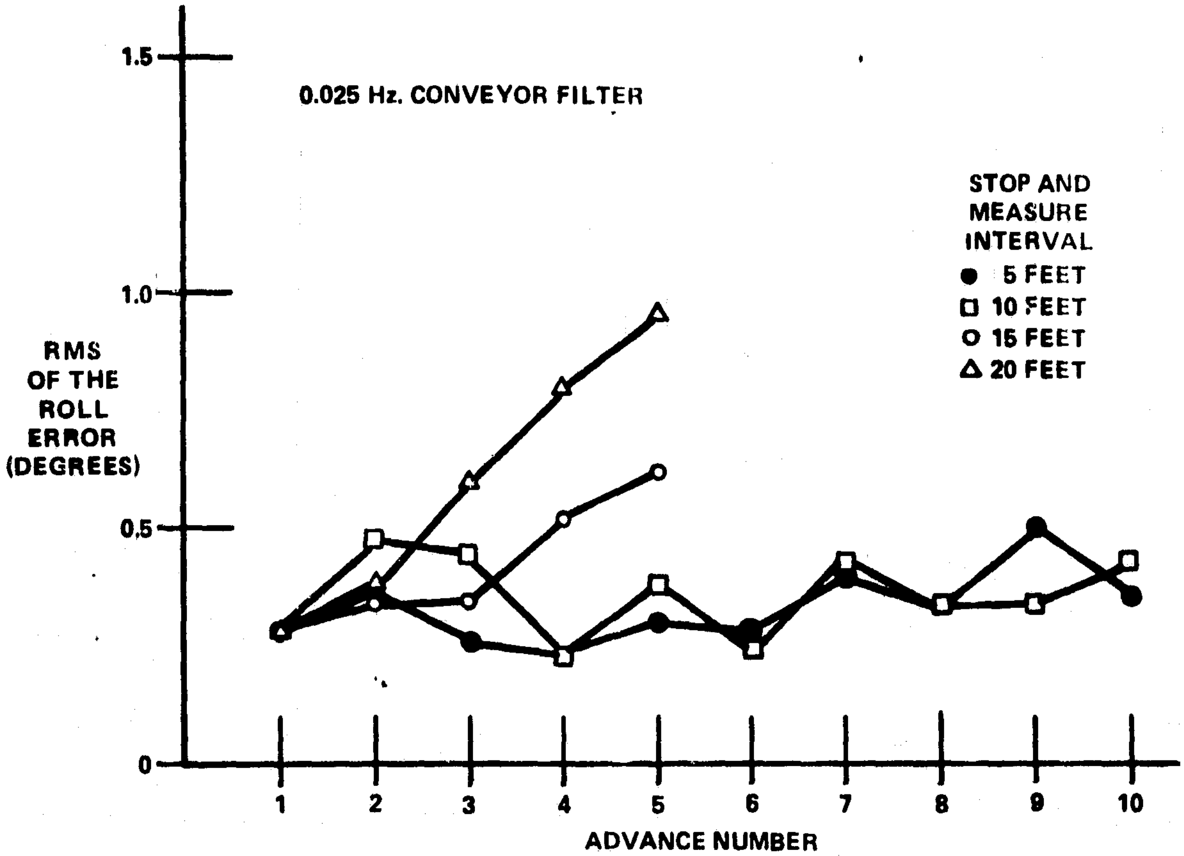

Figure 5-34. Performance Results of the Roll Control System with Inclinometer Mounted on the Shearer

5.4.3 Recommended Roll Control System

The recommended roll control system is the baseline system with the inclinometer mounted on the shearer. Either open or closed loop control is satisfactory in terms of performance.

A system with an inclinometer mounted on a separate cart is a candidate system provided the interval between measurements is small (1 foot). The operational problems using a seperate cart, however, offset any possible performance improvements.

A roll control system using an inclinometer mounted on the shearer and which measures roll without cutting on the clean-up pass is also a candidate system. Simulation results show the system is stable, can tolerate cross axis accelerations as high as 0.2 g's and a sample interval of 5 feet. Implementation requires the inclinometer output to be matched with the shearer roll profile from the previous pass. As a result, the implementation and operation is more complicated and therefore not recommended.

The other alternate roll control concepts are unsatisfactory because they are either unstable systems, they require too many inclinometers or they severely complicate the system operation.

5.5 Conclusions and Recommendations

A roll control system is required to provide an additional degree of freedom to the shearer. It rolls the shearer so that the cutting drums are tilted allowing the conveyor to advance and remain in the coal seam. The control system recommended is one with a inclinometer mounted on the shearer. The inclinometer measures the roll of the shearer with respect to inertial space and commands the shearer roll so that the cutting drums will follow the coal seam. (Provisions must be provided for a bias if the coal seam is not level.)

Either the baseline closed loop or open loop control system is viable. The closed loop system computes the shearer roll angle required and then commands that shearer roll angle. Control actuator feedback is necessary and therefore a position transducer is required. For open loop control the system drives the roll error to zero with a high gain. Actuator feedback is not necessary. Performance of either system is satisfactory. Other roll control concepts studied are either unsatisfactory from a performance viewpoint or from operational considerations.

6. ROLL CONTROL SUBSYSTEM

The roll control subsystem functions to maintain the attitude of the shearer about its roll axis constant in a mining environment that includes substantial time varying cross axis acceleration forces due to conveyor snaking and cutting head irregularities. The servo loops being considered in the shearer design differ in that one implementation contains the inclinometer within the loop while the other implementation uses the inclinometer as an input to a loop that is closed around the hydraulic actuator through an encoder. In both cases the control input to the loop is the "seam incline" digit switch on the MCS. This is an operating parameter and may be introduced into the shearer roll control in real time by the operator. The "shear incline" display is a numeric display of the inclinometer output calibrated to show true gravity normal.

Block diagrams for the two methods of implementation are shown in Figure 6-1, and Figure 6-2. The position loop of Figure 6-1 is shown in analog form although the actual implementation would be by microprocessor using the methods of finite arithmetic to obtain the required transfer functions. The loop of Figure 6-2 is shown as a digital realization of the control loop that contains the inclinometer within it. These transfer functions may also be implemented by the methods described above.

The roll control loop forms part of the ECM electronics on the shearer. Inputs to it (seam incline) from the MCS and outputs from it (shear incline) to the MCS are processed as part of the data exchange through the communications link. This data is formatted, coded and error checked by the MCS microprocessor operating under the "BOSS" monitor in the same way that all other MCS-shearer data exchanges are handled; see Section 7.3 for more detail.

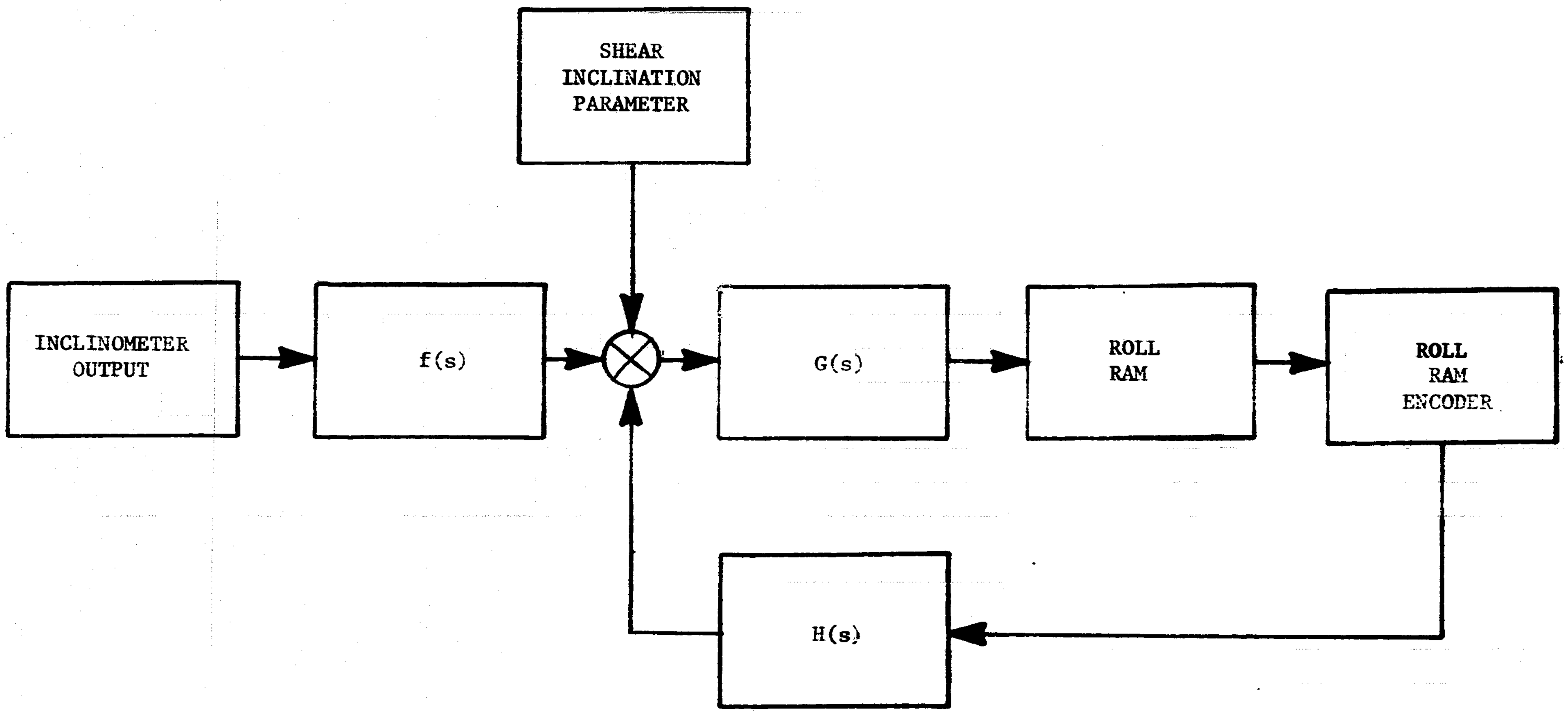

Figure 6-1. Roll Ram Position Servo Loop Implementation

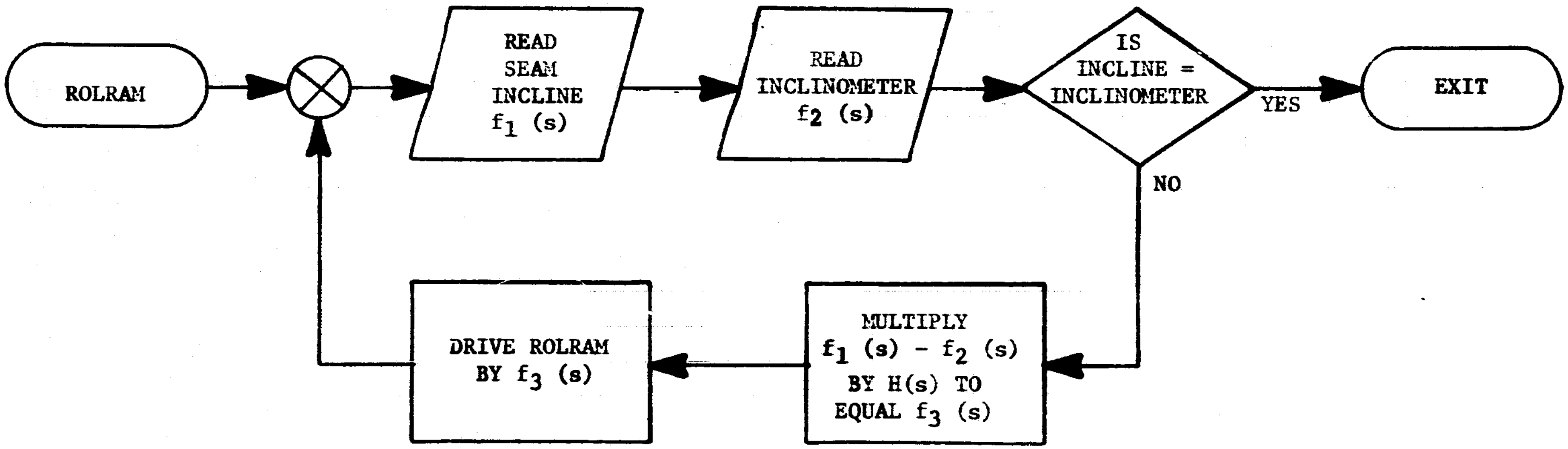

Figure 6-2. Roll Ram Control Loop Implementation

7. MASTER CONTROL STATION DESIGN

7.1 Overall Design Considerations - There are three primary operating modes of the mining system. During the automatic mode, the system is operating independently of a human operator in the active control system. The role of the Headgate man in this mode is to monitor the operation of the system and provide inputs only as necessary to assure the integration of the automatic mining system as a whole with the operation of the shearer and roof support system. During the early development and testing of the system, the man will be required to monitor and evaluate system performance and determine requirements for changes in the design or operation of the system. During on-line operation, the man will be concerned only with the overseeing and judgemental factors necessary to produce coal at the maximum rate. Certain monitoring functions are related to the task which are not reflected in MCS hardware. Two of these concurrent tasks are monitoring of crew performance and monitoring abnormal events in the mining operation. Since these are the normal duties of the Face Boss it would be well for him to spend the majority of his time at the crew station where the MCS is located so that he might monitor crew schedules, maintenance operations, production schedules, set-up and relocation of equipment and a variety of management and supervisory tasks. Monitoring of abnormal roof conditions, blockages in the system, unexpected variations in seam contours, release of ground water, and other abnormal events all affect the operation of the shearer and support systems but are not included in the design of the panel. However, the initial indication of such an off-nominal situation would first likely to appear on the MCS.

The second primary mode of operation is the remote mode. In this mode the Headgate man is required to take an active role in the control of the system as well as continue all the monitoring requirements of the automatic mode. As a design requirement, any control

function that is available to the automatic mode and all sensory imputs available to the automatic mode will be available to the man in the remote mode of operation. The remote mode, while an operational mode, is designed primarily for checkout and calibration.

The third mode of operation is the manual mode. In this mode, the automatic and remote modes are disabled for control purposes and the control of the shearer is accomplished at the shearer through a separate control panel. Monitoring is maintained at the MCS. The design requirement is that no operation of the shearer or the roof support system be effected without the direct supervision or control by the men in the vicinity of the equipment.

There are three non-operating modes. In the power-up mode, power is applied to the system. The requirement is that the application of power shall enable the selection of an operating mode but shall result in no movement of the shearer or roof support and no starting of motors or other moving elements such that men could be endangered or equipment damaged. The default mode, assumed during power up, is the manual mode.

There are two power down modes. The emergency power off mode shuts down all system power except emergency battery power either by the automatic system or by manual input. A non-emergency power down mode allows the system to be partially powered down by an automatic system that can be overridden by the man monitoring and controlling the system.

The fundamental requirement for the operating modes relates to the nature of the control task in mining operations. Consider on the one hand the variations in contour, overburden, structure and other physical facts of the mine and on the other hand the problem of shearing off coal in an efficient manner. The shearer system has to be manipulated or responsive to three axes of translation, X, Y, and Z and three non-Cartesian axes, the "body" axes x, y, and z.

X - The movement of the shearer between the headgate and the tailgate.

Y - The vertical axis perpendicular to X relating to movement of the cutter support arms.

Z - The axis perpendicular to the other two determined by location of the tracks relative to the face.

x - Rotation about the X axis controlled by the roll actuator.

y - Rotation about the Y axis determined by the tracks with no active control on the shearer, the yaw axis.

z - Rotation about the Z axis, determined by the tracks; pitch.

When an operator, or team of operators, is controlling the system by reaction to data that is sensed directly by his eyes, ears, touch, etc., he can sense seam conditions to position his cutters for a fairly efficient operation. With sufficient data, the automatic system can compute solutions to solve the same control problems in a highly efficient fashion. When the man has to use the data available to the automatic system and calculate solutions, he is highly inefficient. While there are a large number of ways of integrating men and machines to efficiently and safely mine coal, the purpose of this study is to develop an automatic system; the remote mode is not a normal operating mode. Nonetheless, it is desired to make the operation in the remote mode as efficient as possible, within this constraint, and data needed to operate the system should be presented in as useable a form as possible so that the operator can selectively assist the automatic system. The remote mode is used to calibrate and checkout the system and provide turnaround control at the end of each pass as an alternative to manual or automatic control. Based on these functional requirements, a system was developed. During all phases of preliminary design, impact on the MCS and operator limits and abilities were considered and the functional requirements were broken down into detail requirements. This breakdown is presented

in a standard functional requirements format presented in Table 7-1, pages 1 through 5 and Table 7-2, pages 1 through 15.

Each functional requirement to display information to the operator or to react to his control commands suggested multiple alternatives among displays and controls and a variety of placements into a control panel and console. Since the system will require changes in function as it progresses toward an operational system, an additional requirement for the MCS portion of the system is to provide for growth and modification. The rationale for panel design, hardware selection, console location and the results of supporting trade studies and cost analyses are presented in the balance of the report concerning Controls and Displays. A summary of functions of controls and displays is presented in Table 7-3.

7.2 Panel Layout - The two major groupings of controls and displays are in the vicinity of the shearer for manual control and at a master control station for remote control and automatic monitoring. The final configurations are expected to differ somewhat from the configurations presented but the major approach is capable of considerable change in detail without changing the comprehension of the controls and displays form the operator's viewpoint.

The master control station includes the display and control panel mounted on a console and positioned where an operator can conveniently use controls and displays. The stage loader with location of MCS is shown in Figure 7-1.

The console allows access through side panels and complete removal of the control and display panel for modification or repair. The console cover protects the MCS from inadvertant activites and damage from supply handling in the area but allows access to the emergency shut down control. The panel layout of controls and displays is presented in Figure 7-2. The grouping is by functions with location of controls and related displays within the functional groups determined by link analysis, criticality, use frequency

Table 7-1. Functional Requirements for Major Modes (Page 1 of 5)

OPERATING MODE	FUNCTION	CONTROL LOCATION	FUNCTION LOCATION	DEDICATED/ ADDRESSED	C/D TYPE	REMARKS
Not Applicable	Turn MCS system power on	Master control station on the stageloader	MCS Stageloader Shearer Roof supports Face conveyor	Dedicated	Lighted pushbutton switch	Immediately after turning MCS system power on, various initialization sequences begin. These sequences include system hardware and software checks, verifications and setup actions such as input register set to zero, counters, set flags and branch conditions initialized, processor instruction set interrogated, excitation voltages verified, switch position and sensor status checked. The later two entities include power & control circuit breakers closed; stageloader, shearer, roof support and face conveyor switch off; pull keys clear; inclinometer, angle cart resolves, sensitized picks both draws, last cut follower, present cut follower, coal interface detector, methane detector/monitor, ionizing radiation detector/monitor, fire suppression low pressure sensor, HALON gas pressure, fire suppression automatic and manual actuation system, shearer chassis position encoder, roof support overload and emergency off circuits energized.
Not Applicable	Verify initialization sequences complete	Master control station on the stageloader	MCS	Dedicated	Status indicator light	When sequencing is satisfactorily completed, a ready light will illuminate. If the sequencing is interrupted, a hold light will illuminate and contingency procedures followed.
Automatic (System Start Up)	Automatic start & turn on of defined system motors, pumps, valves, sensors and controls. The following selections are to be made on the control panel: Seam height/thickness Desired height or	Master control station on the stageloader	MCS Stageloader Shearer Roof supports Face conveyor	Dedicated	1) Lighted pushbutton switches 2) Audible alarm 3) Start/run indicator lights 4) Ammeters 5) Pressure indicators 6) Temperature indicators 7) Capacity, volume, quan-	Automatic start of motors & pumps and positioning of valves & controls including: a) Shearer Pump Motor - with associated 3-sec. audible start-up alarm (preconditions: haulage motor off, haulage speed control to zero and shearer direction switch off). Observe start/run indicator, ammeter, hydraulic pressure (for actuation of drum ranging arms,

NOTE: This table provides a top level functional description used to baseline the mode controls. As a design tool, it is indicative of the design approach.

Table 7-1. Functional Requirements for Major Modes (Page 2 of 5)

OPERATING MODE	FUNCTION	CONTROL LOCATION	FUNCTION LOCATION	DEDICATED/ ADDRESSED	C/D TYPE	REMARKS
Automatic (System Start Up) Con't	thickness of coal to be removed Distance to be maintained between present and previous roof cut horizons Top coal bias or thickness Seam inclination				tity gages 8) Flow meter 9) Status indicator 10) Digital readouts 11) Three position toggle 12) Contact switches 13) Preload indicator 14) CID chamber pressurization sensor 15) Alert lights	cowls & roll/tilt actuators) filter status, hydraulic fluid temperature, & volume. b) Water Control Valve - Provides water flow to haulage motor & cutter motors cooling jackets and to the dust suppression manifold & nozzles. Observe water flow meter and temperature and flow sensor lights. (Spray could be inhibited until shearer advances. Cooling jacket outlet water diverted to a drain system) Observe cooling jacket, outlet water temperature, water filter status, water pressure, and water flow rate. c) Drum/Cutter Motors - Observe start sequence. 1) Both motors, indicator light to START Pump motor indicator back to start 2) Three-second audible alarm 3) Left motor indicator light to RUN 4) Left motor ammeter reading and drum rotation 5) About one-second after left motor is running, observe right motor indicator to RUN 6) Right motor ammeter reading and drum rotation 7) Pump motor back to RUN Cutter motors will automatically deenergize when a critical current or temperature valve is reached. When either cutter motor deenergizes, the haulage motor automatically deenergizes. d) Haulage Motor - (Preconditions: Haulage velocity control in STOP position and shearer chassis direction of travel switch in either TO HEADGATE or FROM HEADGATE) 1) Observe indicator light change from OFF to START to RUN

C-3

Table 7-1. Functional Requirements for Major Modes (Page 3 of 5)

OPERATING MODE	FUNCTION	CONTROL LOCATION	FUNCTION LOCATION	DEDICATED/ ADDRESSED	C/D TYPE	REMARKS
Automatic (System Start Up) Con't						2) Observe ammeter reading. Haulage motor will deenergize when current or temperature reach a critical value. 3) Observe direction of travel indicator light (TO or FROM HEADGATE) 4) Observe distance from headgate digital display 5) Haulage motor will also deenergize when either cutter motor deenergizes e) Face Conveyor Motors - Observe approx. 5-second prestart audible warning. Observe face conveyor tailgate and headgate motor current as the motors start and run. These two motors will deenergize when the current or fluid coupling temperature reaches a critical value. The face conveyor can operate with only one of the two motors in operation. In normal operation, the load is balanced between the two motors. These motors cannot be started from the MCS. These motors will also deenergize when the panel belt stops. f) Stageloader Motors - Observe stageloader right and left side motor current as the motors start and run. These motors will deenergize when the current reaches a critical value or when the panel belt speed reduces sufficiently to cause the roller centrifugal switches to function. These motors cannot be started from the MCS. g) Panel Belt Motors - Observe panel belt motors current. Be aware of current (amps) band in which centrifugal switch turns off panel belt motors with accompanying shut down of stageloader and face conveyor motors. Panel belt motors cannot be started from the MCS.

Table 7-1. Functional Requirements for Major Modes (Page 4 of 5)

OPERATING MODE	FUNCTION	CONTROL LOCATION	FUNCTION LOCATION	DEDICATED/ ADDRESSED	C/D TYPE	REMARKS
Automatic (System Start Up) Con't						h) Pump Motors - Observe roof support & stageloader hydraulic pump motors indicator lights go from OFF to RUN. Observe hydraulic pressure, normal range 2500-3000 psi. The fluid is an oil-water emulsion, 95% water and 5 percent oil. Check fluid temperature and volume in the reservoir. Check filter status. The system functions include stageloader right and left advancing runs, stageloader light and left anchor legs, roof support leg raise and lower, ram push (conveyor push), ram pull (roof support pull up to conveyor) and roof support side shield raise and retract. To provide maximum fluid flow for rapid roof support operation, the pressure drops in the hydraulic system must be carefully controlled. This is a single system for all functions. i) Vertical Control System Sensors - CID LCF & PCF deployment. Observe indicator lights - DEPLOY; CONTACT. The contact light indicator sensor contact with the roof and with the proper preload. The coal interface detector will have associated indicators for chamber pressure integrity and aperature shield position. There is provision for manually stowing the VCS sensor arrays. There are two arrays, one for each drum, and each having a CID, PCF and LCF. The CID is located to the rear of the upper drum, the LCF is deployed from the upper drum to maintain contact with the previous cut roof horizon to maintain a defined and selected height difference between the previous and present cuts. The present roof cut follower is deployed from the bottom drum to maintain contact with the present cut roof horizon. It pro-

Table 7-1. Functional Requirements for Major Modes (Page 5 of 5)

OPERATING MODE	FUNCTION	CONTROL LOCATION	FUNCTION LOCATION	DEDICATED/ ADDRESSED	C/D TYPE	REMARKS
Automatic (System Start Up) Concluded						vides for a constant, selected thickness of coal to be removed and to leave the desired amount of bottom coal, even if the amount is zero. It is also used to verify the distance between the previous and present cut roof heights. The sensors in the array for each drum deploy to the appropriate position as a function of the selected direction of shearer travel. Present top cut follower encoder signals to the bottom drum actuator, provide for the maintenance of the desired distance of the bottom drum to the top present cut. j) Face Lighting System - Observe lighted pushbutton switch in ON position. Address wattage value for indication of number of lights on. k) Face Voice Communications System - Observe lighted pushbutton switch in ON position. Manually position other controls such as audio level and squelch. General: 1) The AUTOMATIC mode control pushbutton switch shall have associated with it a control for position A and position B. Position A is selected when top coal is to left. Position B is selected when it is desired not to leave top coal. This is intentionally redundant to the top coal remaining control. 2) When the AUTOMATIC mode is initially selected, the sequencing indicator light will go from READY to OFF. If there is an anomaly in the AUTOMATIC start up program, the light will indicate HOLD and contingency procedures will be followed. Upon satisfactory completion of the start up procedures, the sequencing indicator light will indicate READY and the AUTOMATIC mode control pushbutton indicator switch will illuminate.

Table 7-2. Functional Requirements Lower Level (Page 1 of 15)

START UP

STEP	OPERATION	OBSERVATION	DISPLAY
	Shearer to be positioned at headgate. Shearer operating mode switch to be in AUTOMATIC mode position.		
1.	Place shearer velocity (Haulage speed) control to 0 fpm or STOP position.	Observe shearer advance speed knob in STOP position.	STOP
2.	Place POWER control to ON position.	Observe illumination of indicator light.	ON
3.	Place MODE SELECT control to AUTOMATIC position.	Observe operating mode light.	AUTO
	If after placing system power ON, the operating mode indicator light displays LOCAL, proceed to the shearer and place operating mode switch to the AUTOMATIC position.		
4.	Press SHEAR HYD control.	Observe 3-second audible alarm prior to motor start. Observe motor start indications - sound, ammeter and indicator light.	START
5.	Wait.	Observe spring-loaded return of control to RUN position upon release from START position. Observe ammeter and hydraulic pressure.	RUN

NOTE: This table provides samples of the working functional requirements that were made prior to the design of the system. Thus, they do not necessarily reflect the final design but indicate the process by which the panel design evolved. A similar format will be used during the detail design and test of the system and be updated and revised for use as operating instructions for the panel.

Table 7-2. Functional Requirements Lower Level (Page 2 of 15)

STEP	OPERATION	OBSERVATION	DISPLAY
6.	Place Water Control to ON position. One control for: a) Shearer cutter motor(s) and haulage motor cooling b) Dust suppression	Observe: a) Control position ON cooling jacket water temperature. b) Water flow through dust suppression system.	a) ON b) Flow gpm c) Temperature
7.	Start shearer drum cutter motors:		
	a) Place shearer motor control to START position	Observe control in START position.	START
	b) Simultaneously place pump motor start/run control to START position	Observe control in START position.	
	c) Hold both switches in START position for approximately four seconds or until both drums are rotating	Observe 3-second audible alarm prior to drum rotation. Observe left drum rotation. About 1 second later, observe right drum rotation.	START
	d) Release both controls to spring loaded RUN position	Observe pump motor control and shearer motor control in RUN position. Observe ammeter and indicator light.	RUN
8.	Place momentary toggle to HEADGATE position (direction of travel)	Observe control in position for direction of travel desired.	TO H

Table 7-2. Functional Requirements Lower Level (Page 3 of 15)

STEP	OPERATION	OBSERVATION	DISPLAY
9.	Deploy vertical control system sensors. Coal Interface Detector, Last (previous) Cut Follower and present top cut follower array.	Observe control in DEPLOY position. Three microswitch, one for each sensor, for roof contact indication. Deployment linkages from both drums. CID located to rear of top drum; present cut top follower is located directly above bottom drum. Encoder signals actuator so as to maintain a constant distance from top cut.	VCS SENSORS DEPLOY
10.	Start face conveyor headgate motor. Place control in START position.	Observe: control in START position, indicator light ON, ammeter and normal belt movement. (One motor alone will drive belt)	START
11.	Start face conveyor tailgate motor. Place control in START position.	Observe control in START position, indicator light, ammeter and normal belt movement.	START
12.	Start stage loader right-side motor. Place control in START position.	Observe: control in START position, indicator light, ammeter and normal belt movement.	START
13.	Start stage loader left-side motor. Place control in START position.	Observe: control in START position, indicator light, ammeter and normal belt movement.	START
14.	Enter/Set seam height. Position controls to indicate seam height.	Observe display reading seam height value.	SEAM THICKNESS (inches)
15.	Select amount of top coal desired to be left.	Observe display indicating HEAD COAL REMAINING at selected value.	HEAD COAL REMAINING (inches)
16.	Select amount of bottom coal desired to be left.	Observe display indicating BOTTOM COAL remaining at selected value.	BOTTOM COAL (inches)

Table 7-2. **Functional Requirements Lower Level (Page 4 of 15)**

STEP	OPERATION	OBSERVATION	DISPLAY
17.	Energize sensitized picks, top drum. Place control to ON position.	Observe control in ON position and sensitized pick output level.	ON
18.	Energize sensitized picks, bottom drum. Place control to ON position.	Observe control in ON position and sensitized pick output level.	ON
19.	Energize last (previous) cut follower. Place control to ON position.	Observe control in ON position and encoder output.	ON
20.	Energize present top cut follower.	Observe control in ON position and encoder output.	ON
21.	Energized Coal Interface Detector.	Observe: cotrol in ON position; coal thickness reading	ON COAL THICKNESS (inches)
22.	Energize ionizing radiation meter.	Observe: control in ON position; rem reading	ON rem units
23.	Place roof support hydraulic pump in the ON position.	Observe: control in ON position; hydraulic pressure.	ON HYD. PRESS (Dsi)
24.	Place stage loader hydraulic pump in the ON position.	Observe: control in ON position	ON (psi)
25.	Enter seam verticality orientation data, (pitch, slope, inclination).	Observe thumbwheel entry	

Table 7-2. Functional Requirements Lower Level (Page 5 of 15)

STEP	OPERATION	OBSERVATION	DISPLAY
26.	Set in values on alignment system.	Observe settings.	THUMBWHEELS
27.	Place face lighting control to ON position.		ON
28.	Place face voice communications system control to ON	Observe control in ON position	ON

Table 7-2. Functional Requirements Lower Level (Page 6 of 15)

CHECKOUT/CALIBRATION

STEP	OPERATION	OBSERVATION	DISPLAY
1	Check all electric motor currents Shearer pump Shearer left drum Shearer right drum Haulage Face conveyor tailgate Face conveyor headgate Stageloader right Stageloader left Panel belt Roof support hydraulic No. 1 Roof support hydraulic No. 2	Observe ammeter reading	AMPERES
2	Address processor (computer) for left drum cowl position	Observe digital readout	OK
3	Address processor (computer) for right drum cowl position	Observe digital readout	OK
4	Address processor (computer) for shearer location	Observe digital readout	NUMERICAL VALUE
5	Address roof support pullup data (last pull-up event)	Observe digital readout	NUMERICAL VALUE
6	Observe shearer roll angle: present and desired	Observe digital readout	ROLL ANGLE (Degrees)

Table 7-2. Functional Requirements Lower Level (Page 7 of 15)

STEP	OPERATION	OBSERVATION	DISPLAY
7	Place roll actuator control to INCREASE position	Observe: Control position to increase position; observe roll angle change	INCREASE; Digital readout (Degrees)
8	Place roll actuator to DECREASE position	Observe: Control position to decrease position; roll angle change	DECREASE; Digital readout (Degrees)
9	Place left drum control to raise position	Observe control position; linear actuator position	RAISE; Digital readout (Inches); Pointer position
10	Place left drum control to lower position	Observe control position, linear actuator position	LOWER; Digital readout (Inches); Pointer position
11	Place shearer velocity control to fpm position and address cowl position	Observe control position; observe shearer movement away from headgate; observe haulage motor, current, cowl position	2 fpm FROM H AMPS OK
12	Place shearer velocity control to STOP position	Observe control position; observe shearer stop, observe haulage motor current	STOP FROM H AMPS
13	Place shearer chassis drive motor (haulage) control to the TO headgate position and address cowl position	Observe control position; haulage motor current; cowl position	TO H AMPS OK
14	Place shearer velocity control to 2 fpm position	Observe control position; observe shearer movement toward headgate; observe haulage motor current	TO H AMPS

Table 7-2. Functional Requirements Lower Level (Page 8 of 15)

STEP	OPERATION	OBSERVATION	DISPLAY
15	When shearer reaches headgate position, place shearer velocity control to the STOP position.	Observe control position, observe shearer stop, observe haulage motor current.	STOP TO H Amps
16	Place shearer chassis drive motor to the away from headgate position and address cowl position.	Control position; haulage motor current, cowl position.	FROM H Amps OK
17.	Check shearer hydraulic system fluid temperature, volume and flow.	Observe pump motor indicator light; temperature gage; flow meter and fluid quantity gage.	ON of gpm gal.
18.	Check roof support; and stage loader hydraulic systems.	Observe pump motor indicator light; temperature gage; flow meter and fluid quantity gage.	ON of gpm ga.
19.	Roof support function, face advance and Yaw alignment elements (randomly select a discrete roof support or block supports with view of MCS operation). Raise and lower legs; raise and lower shield; push and pull ram,	Control position; roof load indicator; ram position, fall conveyor alignment; hydraulic pressure.	ROOF LOAD psy, Digital Readout, Gage: psi
20.	Function the stage loader positioning elements; 2 roof jacks and 2 advancing rams.	Control position, ram position, stage loader movement, hydraulic pressure.	Direct observation of stage loader element; gage psi.
21.	Last cut follower encoder check; address the processor.	Digital readout.	NUMERICAL VALUE

Table 7-2. Functional Requirements Lower Level (Page 9 of 15)

STEP	OPERATION	OBSERVATION	DISPLAY
22.	Present top cut follower encoder check; address the processor.	Digital readout.	NUMERICAL VALUE
23.	Check output signal: sensitized picks - both drums: a) Insure cutter in coal b) Raise cutter until coal; coal interface crossed c) Update processor, sensitized pick threshold values for coal and coal.	a) Observe outputs while in coal b) Observe outputs while crossing coal - coal interface and while in coal c) Observe acknowledgement of new data entry	a_1) COAL a_2) digital read-out b_1) COAL b_2) digital read-out c_1) ACKNOWLEDGE c_2) digital read-out
24.	Calibrate Coal Interface Detector.		
	a) Advance shearer and cut coal so as to leave more than 1 foot roof coal.	a) CID output	Roof Coal thickness (inches)
	b) Take a roof core sample about 20' from headgate ensuring penetration of coal, coal interface	b) Depth or top coal (coal layer thickness) (actual measurement)	
	c) At CID maximum averaging time, record number of counts for coal thickness measured in b)	c) Number of counts	
	d) Measure core hole depth	d) Actual measurement	

Table 7-2. Functional Requirements Lower Level (Page 10 of 15)

STEP	OPERATION	OBSERVATION	DISPLAY
24.	Concluded		
	e) Elevate cutter drum approximately 2 inches	e) Coal thickness readout	Coal thickness digital readout
	f) Measure hole depth	f) Observe new coal thickness reading	
	g) At CID maximum averaging time, record number of counts for coal thickness determined from measurement in f)	g) Number of counts	
	h) Repeat steps d) through g) until desired calibration is obtained.	h_1) CID output h_2) Actual coal thickness measurement h_3) Number of counts	Roof Coal thickness (inches)
	i) Input new calibration data into computer or updat existing calibration table by appropriate constant multiplication.	i) Observe acknowledgment of new data entries	ACKNOWLEDGE
25.	a) Compare shearer mounted methane monitor concentration reading with reading from another MSHA approved and calibrated detector.	a) Observe digital readout from both meters	Methane Concentration Levels Percentage
	b) Calibrate shearer mounted detector/monitor.	b) Digital readout	Digital readout

Table 7-2. Functional Requirements Lower Level (Page 11 of 15)

STEP	OPERATION	OBSERVATION	DISPLAY
26.	a) Compare shearer mounted radiation detector readings with another MSHA radiation meter.	a) Observe digital readouts from both meters	rem readout
	b) Calibrate shearer	b) Digital readout	rem digital readout
27.	Verify processor roof load indicator to be within defined limits.	Digital readout	Digital readout NUMERICAL VALUE
28.	Compare shearer inclinometer output with the output of a test inclinometer temporarily attached to the shearer frame.	Digital readout and direct reading from test instrument	Shearer Roll (degrees) Test ins[illegible]ment direct reading
29.	Check angle cart resolver output to be within specified limits (calibration procedures to be determined).	Digital readout	NUMERICAL VALUE
30.	Verify shearer location encoder.	Observe processor indicated location with actual location	Digital readout and actual location observation
31.	Check mine electrical power supply.	Verfiy proper voltage and frequency.	VOLTAGE HZ
32.	Check shearer frame pitch angle.	Observe processor digital pitch angle output.	NUMERICAL VALUE

Table 7-2. Functional Requirements Lower Level (Page 12 of 15)

STEP	OPERATION	OBSERVATION	DISPLAY
33.	Check shearer water system parameters.	Observe temperature (note Δ since start of cutter motors and haulage motor); pressure and flow.	^{o}F psi gpm
34.	Face lighting check.	Wattage reading; value is indication of number of lamps.	WATTS
35.	Test voice communication system.	Observe aural output	(Aural input to ear)
36.	Check caution and Warning Panel parameters.	Observe proper alert (audible and visual) for all C&W parameters. Check MASTER alarm signal for each C&W parameter CID, CCF, PCF, YAW, ROLE, water temp, flow, pressure; hydraulic temp, flow, pressure; methane, radiation, electrical power V&f; Δ LCF and present cut more than ± 2.0", inadequate R.S. pullup rate.	LIGHTS DIGITAL READOUT

Table 7-2. Functional Requirements Lower Level (Page 13 of 15)

AUTOMATIC

STEP	OPERATION	OBSERVATION	DISPLAY
1.	Monitor VCS performance.	Observe: Top and bottom coal remaining Top L&R ranging arm linear actuator positions desired position, actual position Sensitized pick coal/no coal	Digital readout Digital readout Pointer position coal/no coal
2.	Manually override VCS system.	Observe ranging arm linear actuator and pointers.	Digital readout Pointer position
3.	Monitor Yaw and face advance performance.	Observe Yaw error nulling Observe roof pull-up and conveyor position data. Observe conveyor profile after cleanup run.	Digital readout Pointer position Addressed data
4.	Manually override face advance and Yaw alignment system.	Observe roof support pull-up and conveyor position data. Observe conveyor profile after cleanup pass.	Digital readout Addressed data
5.	Monitor roll performance data.	Observe roll actuator desired and and actual position. Observe roll error nulling.	Digital readout Panel position
6.	Manually override Roll Control system.	Observe roll actuator positioning	Digital readout Addressed data
7.	Monitor motor currents.	Observe motor current in normal range.	AMPS
8.	Override systems as required per motor current reading; change shearer advance velocity and conveyor drives as required.	Observe motor current Shearer cutters Shearer drive (haulage) Face conveyor Stage loader Panel belt	AMPS

Table 7-2. Functional Requirements Lower Level (Page 14 of 15)

LOCAL
(With Shearer at Headgate)

STEP	OPERATION	OBSERVATION	DISPLAY
1.	Position Mode Control selector to LOCAL.	Observe operating mode light.	LOCAL
2.	Proceed to Shearer and place mode control selector to LOCAL.	Observe operating mode light.	LOCAL
3.	Position cowls in location consistent with shearer direction of travel.	Cowl position.	Control position. Cowl position.
4.	Function shearer roll/ tilt actuators.	Shearer roll orientation.	Control position. Cowl position.
5.	Function ranging arm, L & R.	Cutter drum position.	Control position. Drum position.
6.	Change shearer longitudinal position.	Observe shearer movement.	Control position. Shearer position.
7.	Exercise test panel.	Meter readings.	AMPS VOLTS
8.	Function roof support controls.	Roof support actuator movements; legs and ram.	Control position. Roof support element position.
9.	Function stage loader controls.	Stage loader anchor jacks and advancing ram movements.	Control position. Stage Loader element position.

Table 7-2. Functional Requirements Lower Level (Page 15 of 15)

SHUT DOWN

STEP	OPERATION	OBSERVATION	DISPLAY
	Reverse of START UP procedure.		

Table 7-3. List of MCS Controls and Displays (Page 1 of 7)

GROUP	CONTROL OR DISPLAY	PURPOSE	FLOW CHART
Alignment & Roof Support	Thumbwheels - Straightness, Headgate Correction, Tailgate Correction, Criteria	Set in parametric values to determine when Yaw correction should take place. "Straightness" determines the degree of straightness desired as a compromise between maximum straightness possible and maximum track advance for production. "Criteria" sets the limits on deflection of maximum loss minimum outby. "Correction" at each gate is the correction of the computed end point needed to coincide with the measured end point.	**FRSUP Figure 7-9**
	Toggle	Select one of three programs to advance the track. Some rams are actively commanded and some are unlocked and floating. Loss of commands to a particular ram may necessitate selection of alternative program.	**REMOT Figure 7-14**
	Malfunction LED's	Alerts operator to system that is not functioning normally.	**ERRIT Figure 7-12**
	Malfunction Address	Gives location of malfunction by shield number.	**DASGO Figure 7-15**
	Max. Deflect Numeric Display	Shows straightness of track by difference between the greatest and least Outby. This observed number can be compared with the parametric command.	**FRSUP Figure 7-9**
	Seam Incline Thumb Wheel	Sets the geological estimate of seam inclination.	" "
	Shear Incline Numeric Display	Measured inclination of the shearer from the inclinometer.	" "

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Table 7-3. List of MCS Controls and Displays (Page 2 of 7)

GROUP	CONTROL OR DISPLAY	PURPOSE	FLOW CHART
Sensors	CID Thumbwheels A,B,C,D,E	Set in values of constants and **exponents** for calibration of CID.	**FRSUP Figure 7-9**
	CID Thumbwheel Head Coal	Set in value for head coal remaining desired to meet geological recommendation.	" "
	CID Numeric Display, Head Coal	Measured reading of head coal remaining.	" "
	CID Indicator Switches, Stow/Deploy	Monitor of automatic system deploy and stow of each CID. Command stow/deploy of each CID.	" "
	CID Indicators Contact	Provides confirmation that CID is in contact with roof, preloaded by correct pressure and is in all ways ready to provide data.	" "
	Pick Indicators, Lead and Following	Provides indication of either coal or no coal readings from the picks.	" "
	Pick, Thumbwheel, Sensitivity	Input for parametric data on pick sensitivity.	" "
	Followers, Indicator Switches, Present Cut Follower/Last Cut Follower (PCF/LCF)	Indicators show position of followers at position to measure last cut or present cut. Switches command change from one position to another.	" "

Table 7-3. List of MCS Controls and Displays (Page 3 of 7)

GROUP	CONTROL OR DISPLAY	PURPOSE	FLOW CHART
Sensors (Concluded)	Followers, Indicator Switches, Deploy/Stow	Indicators show position of followers as stowed or deployed. Switches command deploy or stow.	**FRSUP Figure 7-9**
	Followers, Indicators, Contact	Show followers are in contact with roof, ready to provide data.	" "
	Followers Thumbwheel, Successive Cut Difference	Input parametric data on difference between present cut and last cut; determines when followers will override other sensors in commanding drum position.	" "
	Indicators, Vertical Control, CID, Picks, Followers	Indicate which of the sensors is commanding vertical position of lead drum. If CID command is overridden by pick, the pick indicator will light; if followers override, the follower will light.	" "
Emergency	Latching Push Button, Emergency Off	Commands power off to all mining operations by direct line to main power station. Works as alternative to automatic emergency power down.	**NOT SOFTWARE CONTROLLED**
	Indicator Switch Fire System	Indicates when fire system on shearer has been initiated and provides manual input command to initiate fire suppression system.	**FRSUP Figure 7-9**
Mode	Indicator Switch Power On	Initiates power to shearer systems and console.	" "
	Indicator Switches, Automatic, Manual, Remote	Selects mode of operation.	" "

Table 7-3. List of MCS Controls and Displays (Page 4 of 7)

GROUP	CONTROL OR DISPLAY	PURPOSE	FLOW CHART
Mode (Concluded)	Indicator Switch, Clean Up Pass	Commands clean up pass.	**REMOT Figure 7-14**
	Indicator, Sequence Ready/ **Hold**	Ready indication lights when mode select command has been completed and systems are ready.	**FRSUP Figure 7-9**
	Indicators, **LED** Cowl	Shows when **cowls** are placed in the appropriate orientation for direction of shearer travel.	" "
Status	Lasting Indicators: Methane, Radiation, Fire, Power	Provides indication of what event caused loss of power. Indicators are reset manually.	" "
	Indicators, LED, Methane, Hydraulic, Sensors, Battery, Fire System, Shields	Indicates normal status (green), off - nominal (amber) and beyond limits (red). Methane and Fire System has no red because upper limit shuts down power. Primary purpose is to have quick-look green indications with a secondary purpose to start a fault isolation search.	" "
	Numerical Indicators, Amps; Panel Conveyor Motor, Left & Right Stageloader Motors, Headgate End Conveyor Motor, Tailgate End Conveyor Motor, Left & Right Cutter Motors, and the Haulage Motor	During start up of motors, amperage indication will show current draw. **Displays** are left to right and top to bottom in start sequence. During the operational modes, these indicators provide information about the mine system that can be overloaded by production rate or by blockages.	" "

Table 7-3. List of MCS Controls and Displays (Page 5 of 7)

GROUP	CONTROL OR DISPLAY	PURPOSE	FLOW CHART
Status (Concluded)	Indicator Switch and Speaker (not shown) Alarm	The alarm is triggered by an out of tolerance state of the systems monitored. The indicator flashes continuously once initiated but the operator can discontinue the audible by the switch. A second out of tolerance re-starts the audible.	FRSUP Figure 7-9
Address Data	Numeric Display	Shows address and data. Address is in hexidecimal, data is decimal.	" "
	Keyboard	Used to address the shearer memory system and change memory print out memory or command reading to the numeric display.	DASGO Figure 7-15
	Key Switch	Enables all commands to the keyboard.	" "
	Press to Test Switch	Tests console lamps.	FRSUP Figure 7-9
	Jacks	Provides plug in point for recorder to receive data from memory.	DASGO Figure 7-15
Shearer	Hydraulic, Numeric Indicators	Shows quantitative information on shearer hydraulic status.	FRSUP Figure 7-9
	Indicators, LED, Hydraulic Filter	Show green, amber, red status of filter.	FRSUP Figure 7-9

Table 7-3. List of MCS Controls and Displays (Page 6 of 7)

GROUP	CONTROL OR DISPLAY	PURPOSE	FLOW CHART
Shearer (Continued)	Water, Numeric Indicator	Shows gallons per minute of water used for cooling and dust suppression.	**FRSUP Figure 7-9**
	Indicators, LED, Water Temperature and Pressure	Shows green, amber, red status indications.	" "
	Indicators, Numeric, Left & Right Cutter	Shows position of cutters relative to a reference point. Used for checkout.	" "
	Momentary Toggles, Raise/Lower	Commands position of cutters during checkout or remote mode.	**REMOT Figure 7-14**
	Thumbwheel, Seam Thickness	Provide parametric data from geological survey used to calculate cutter heights.	**FRSUP Figure 7-9**
	Indicator, Numeric, Roll Actuator	Used to show actuator extension for roll control during checkout and during mining.	" "
	Toggle, Momentary, Roll Ram Tilt, Increase/Decrease	Used to command roll during checkout.	**REMOT Figure 7-14**
	Indicator Switch, Water ON/OFF	Monitor water supply on or off commanded by automatic system. Allows command during checkout.	**FRSUP Figure 7-9**

Table 7-3. List of MCS Controls and Displays (Page 7 of 7)

GROUP	CONTROL OR DISPLAY	PURPOSE	FLOW CHART
Shearer (Concluded)	Thumbwheel, Bottom Coal	Provides parametric data used to calculate distance from present cut follower to trailing drum.	FRSUP Figure 7-9
	Indicator, Numeric Span	Indicates distance between present cut follower and trailing drum.	" "
	Toggles, Momentary, Left Cowl, Right Cowl, Clockwise, Counter Clockwise	Commands position of cowls during checkout.	REMOT Figure 7-14
	Indicators, LED, Direction of Travel, To Headgate, From Headgate	Indicates shearer direction of travel commanded.	FRSUP Figure 7-9
	Toggle, Momentary, Direction of Travel	Commands shearer direction of travel.	FRSUP Figure 7-9
	Numeric Display, From Headgate	Shows distance of shearer from headgate in feet.	" "
	Rotary Switch, Haulage Rate	Sets speed of travel of shearer.	" "

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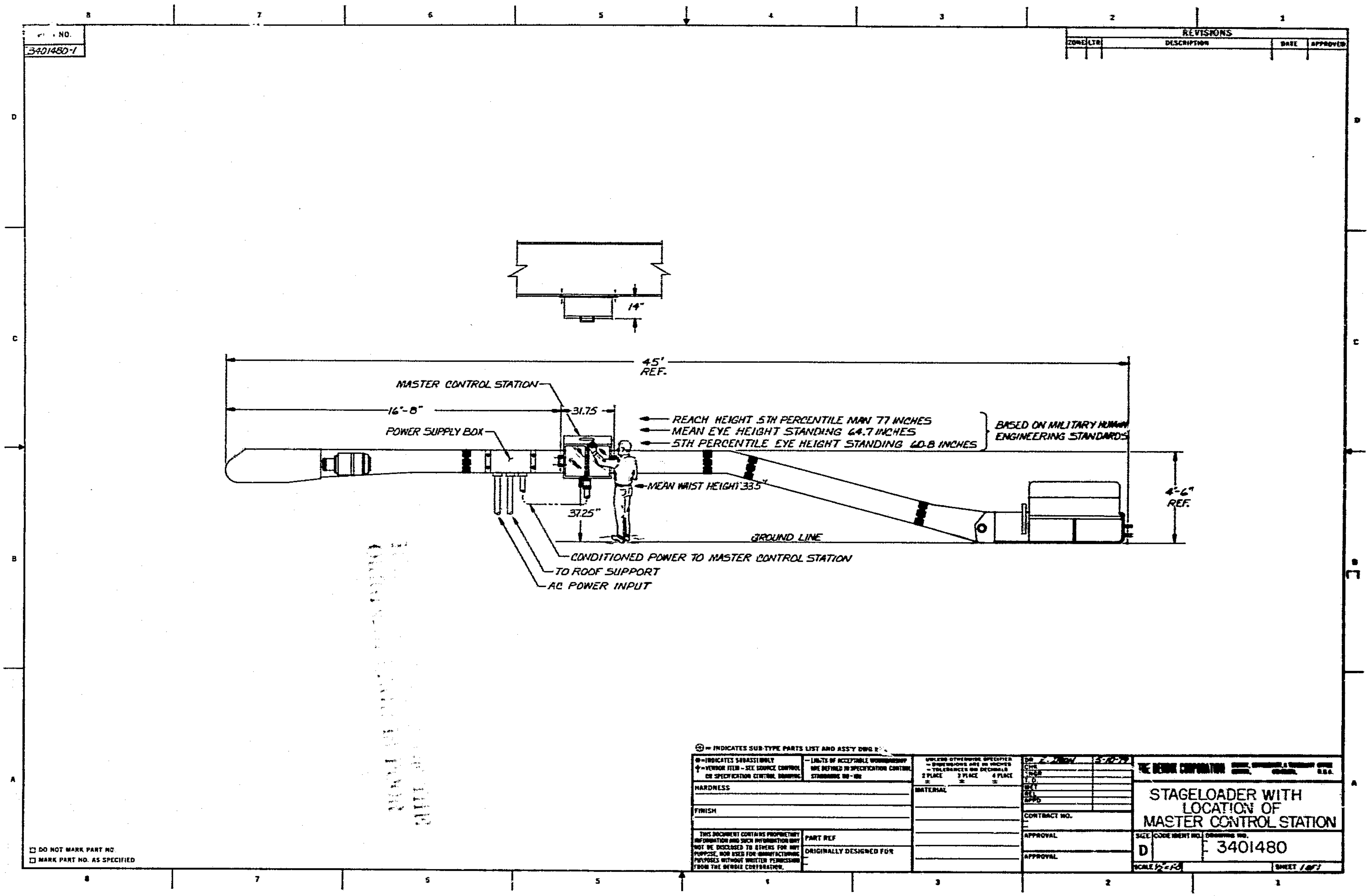

Figure 7-1. Stageloader with Location of Master Control Station

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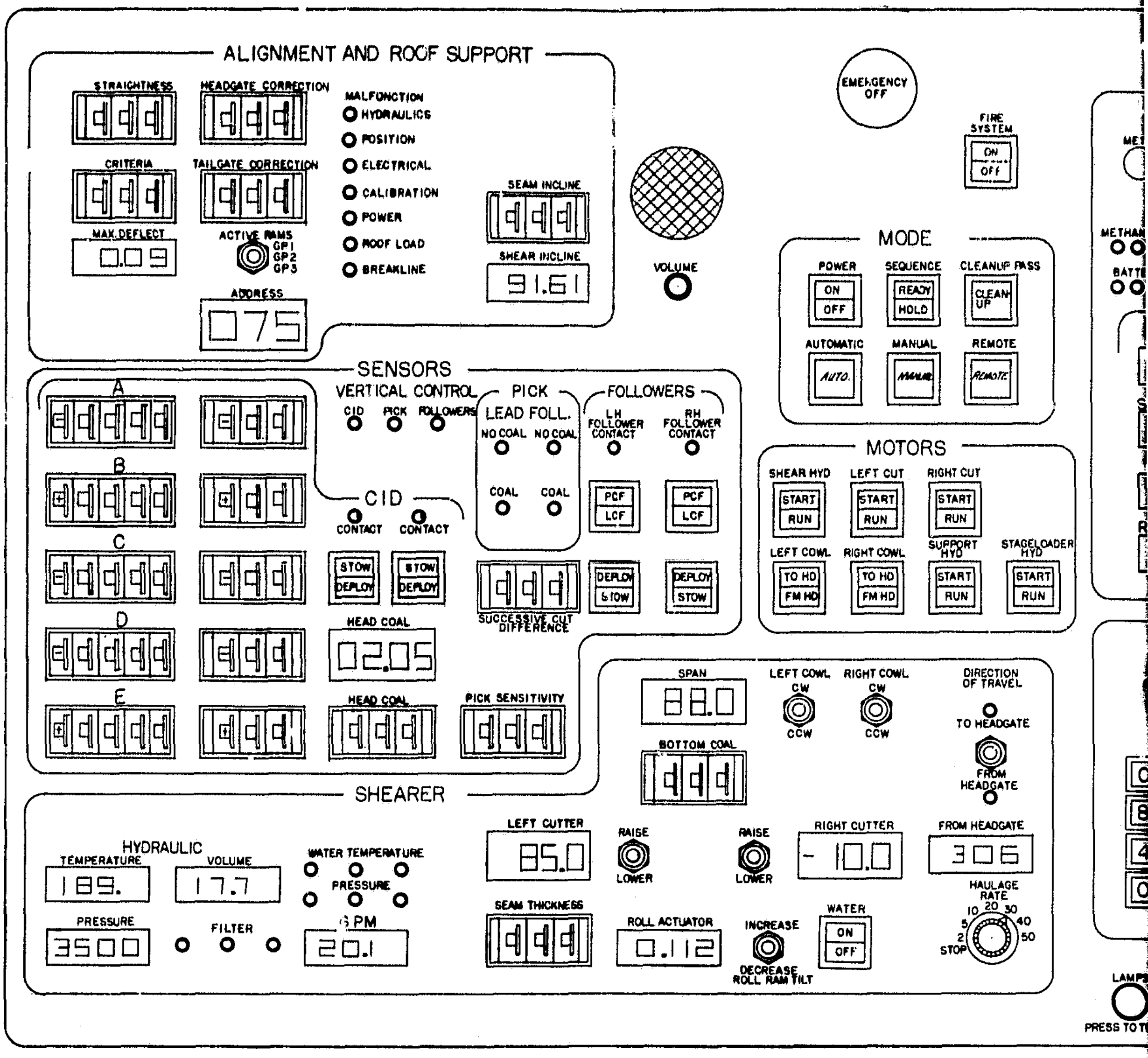

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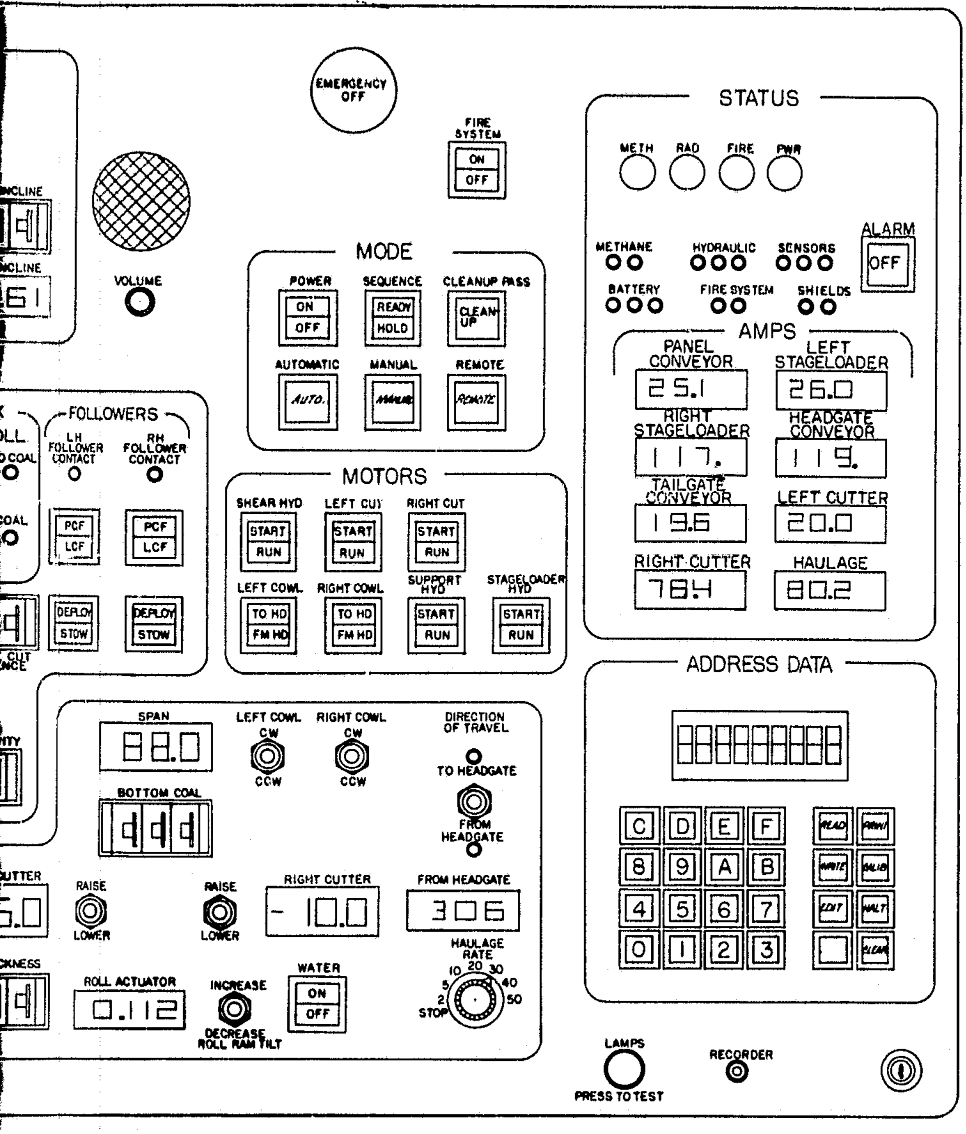

REVISIONS

DRAWN	E. IRON	4-10-79

THE BENDIX CORPORATION — ENERGY, ENVIRONMENT & TECHNOLOGY OFFICE, DENVER, COLORADO, U.S.A.

HEADGATE CONTROL & DISPLAY PANEL

SIZE E — DRAWING NO. 3401349

SCALE FULL — SHEET 1 of 1

Figure 7-2

and consideration for maintenance and assembly requirements. The results of these analyses are presented in Figures 7-3 through 7-6.

Controls and displays are of two types: dedicated and addressed. The address system allows the operator to call up information and command any aspect of the automatic system in the automatic or remote modes and to display any information in the manual modes of operation and in the power up mode. When the emergency power-off mode has been initiated, the address system can not be used. The system can also be used to initialize the memory registers after a power interruption.

All of the information and command capabilities needed to operate the system are presented in dedicated displays and controls. Most controls are momentary so the system state is provided by displays either integrated with the switch or presented in the vicinity of the switch. Momentary switches are used because the parallel use of the address system precludes the use of hard wire logic inputs. Parametric data is not subject to this constraint and is entered via digit switches.

The functional groups are presented in Figure 7-2. The address system consists of an alpha numeric display, a keyboard with hexidecimal characters, process commands and precoded address commands used for information frequently called up, and an entry enabling lock and key. The lock and key is used to control access to the command function of the system so that only selected operators can use the full system capability.

The status grouping consists of amperage monitors for the motors, status indications by major groupings and mechanically locked status indicators triggered by the signals that initiate an emergency power down mode. The latter enable the operator to determine the cause of the emergency power down so that appropriate corrective action can be taken. By glancing at the status panel group, the

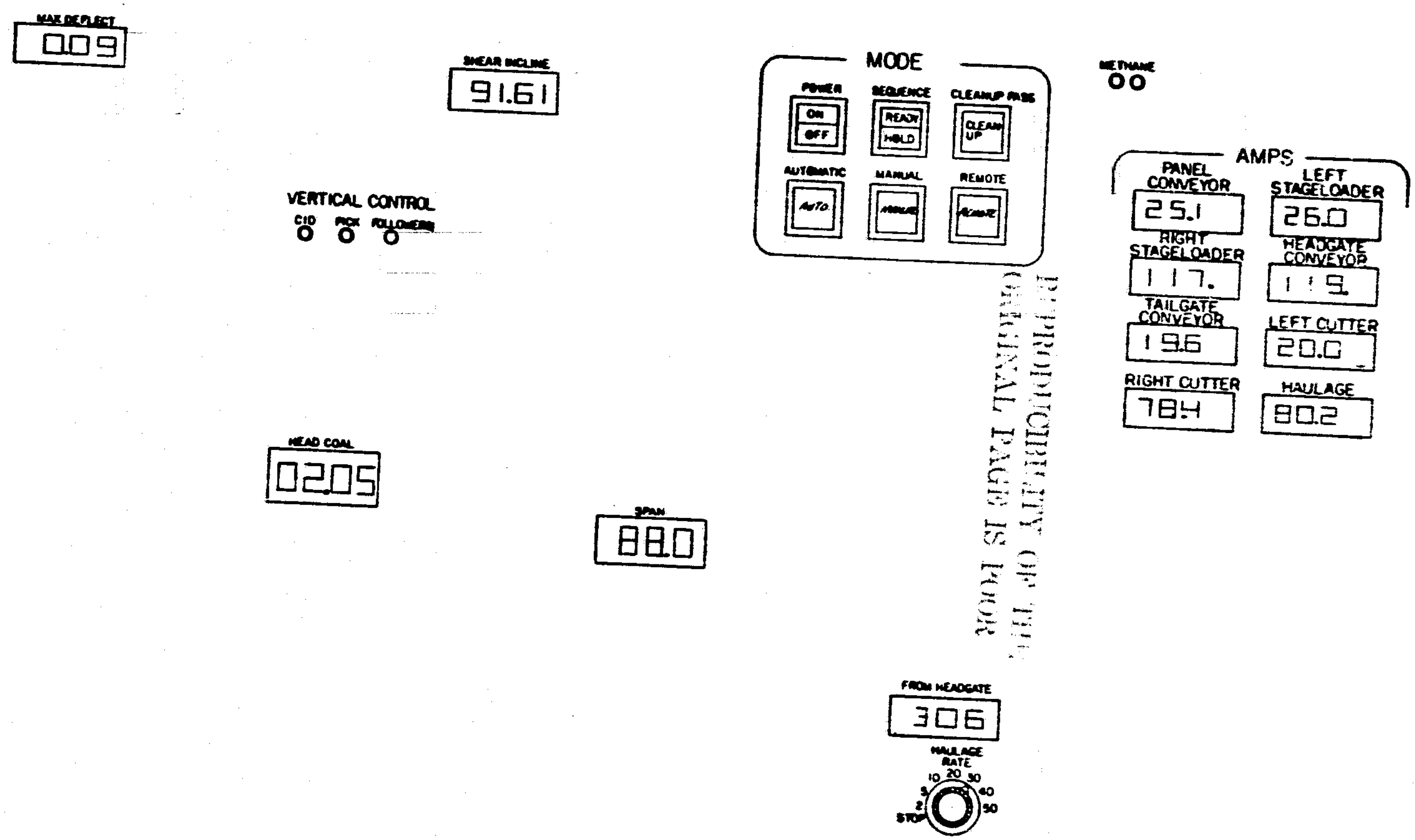

Figure 7-3. Frequently Monitored Displays

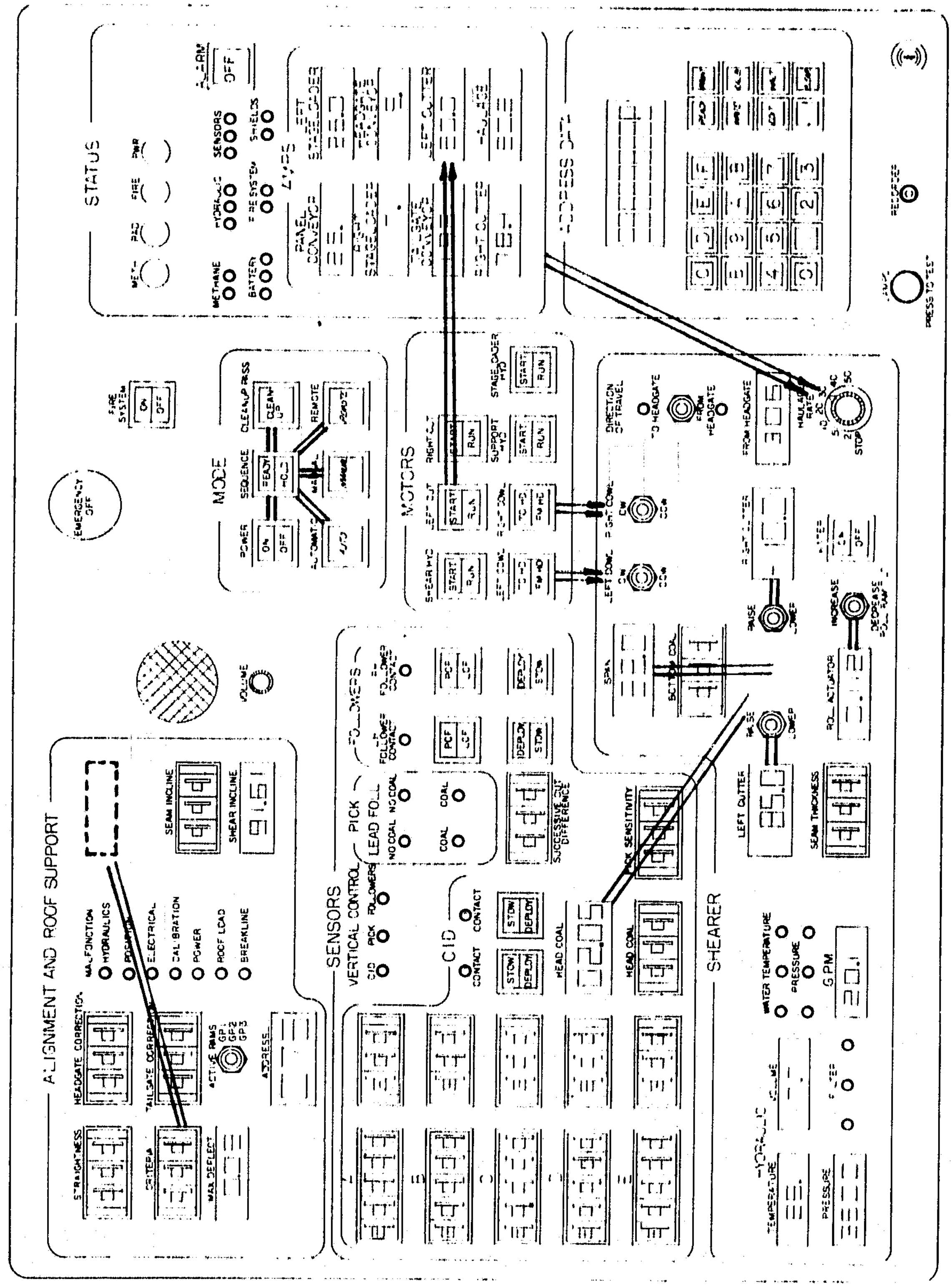

Figure 7-4. Links Among Controls and Displays

Figure 7-5. Critical Controls

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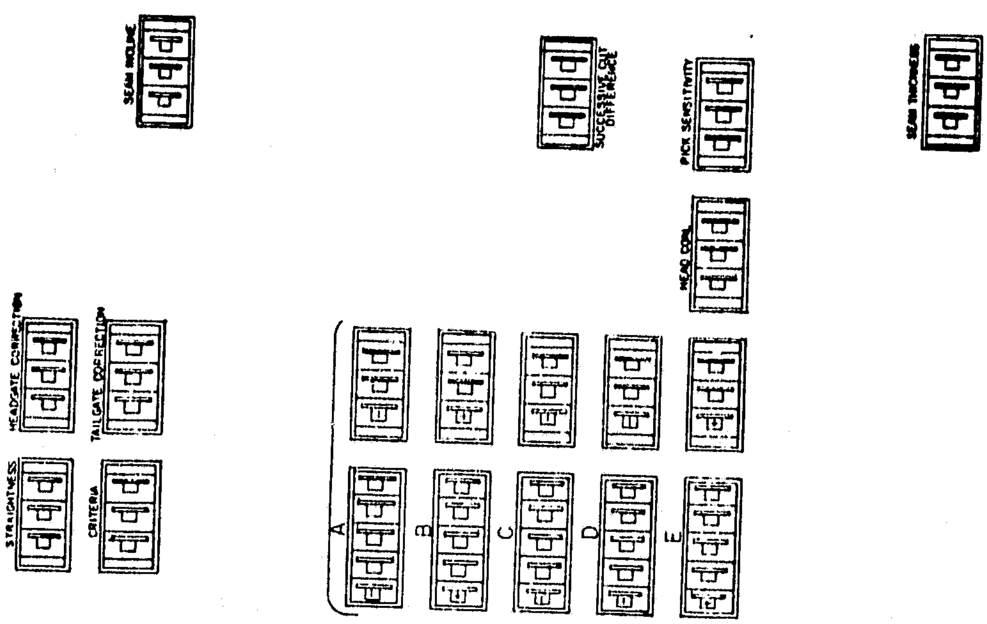

Figure 7-6. Parametric Data Inputs

operator is given green light indications that all systems are functioning normally or if they are not, he is alerted to the grouping that is not functioning normally. If the abnormality is not indicated by a dedicated display he can call up the information with the address system.

The mode selection group consists of indicator-switches to select the mode desired and an indicator that informs the operator when the mode selected is ready or if a hold has occurred in the automatic sequencing. In order to get into the romote mode, the operator must engage the key in the address system area.

The emergency off switch and the fire suppression initiation switch are separated from the other panel areas.

The sensor packages have a dedicated area that allow the operator to monitor the performance of each of the packages. A contact signal assures the operator that the sensor is in the correct position and ready to provide data. If a particular sensor is being overridden by another sensor, an override indication is provided by a set of three displays with the controlling sensor illuminated and the others not illuminated. In most instances the CID indicator will be the only one lighted. The operator can deploy or stow the sensors in the remote mode and has indications of the changing of status when the automatic system is commanding the changes.

The alignment functional grouping displays the amount of yaw deflection, and malfunction indications. Thumbwheel digit switches are used to input parametric data. The actual roll inclination and a dial-in reference of seam inclination based on geological data are in this group. The roll command and display needed for checkout is in the shearer group.

The controls and displays needed to operate the motors are grouped following the normal start sequence, that is, the motor normally started first is at the upper left and the last started is at the lower right.

The grouping on the shearer functions follows linkage and frequency of use criteria in the layout. The principal control is the haulage rate command since this control sets the limits of production rate and any problems in the total system require a rate decrease. If the automatic system halts the shearer, the operator must set the control to stop before the restart sequence can be completed. If the operator has not set in a rate and direction of travel, the automatic system can not operate.

The operator monitors system parameters as dedicated displays in the preliminary design because of a requirement for evaluation of the impact of the automatic mode on shearer systems. Those displays have been placed where their possible removal for operational use will not impact the panel layout in the central control areas.

The cutter height commands are centrally located and near the data displays that are derived from the C.I.D. sensors.

The remaining panel area is used for ancillary controls and displays and a reference material area. The reference material is provided in note book form on protected pages showing system schematics, addresses for the data address system, operating procedures, trouble shooting information, logs, and such other material that the operator may require.

Figure 7-3 shows the location of displays which are frequently monitored. Those on the left relate to shearer operation and sensory data. Those on the right relate to total operations. Other factors being equal, it is good practise to keep associated controls and displays contiguous. The links are shown in Figure 7-4 emphasizing the links between major groups. The total panel approach is to group by system and at the same time centralize the controls. The tradeoff between linkage considerations and other considerations can be seen by reference to the maximum deflection display in the alignment of roof support group. If it is important to keep the frequently

monitored displays central the display should be as shown. If it is more important to shorten links, the display should be placed under the criteria thumbwheel in the same group.

Only a few controls are critical in that they could require a rapid response. These are shown in Figure 7-5. Those frequently used are at hand height. The emergency off is at eye height and central to prevent accidental activation and still make it easy to locate.

The thumbwheels used to input parametric data have been located on the left side of the panel with the most frequently changed centrally located. Since some of these are linked to other displays or are a part of a major group, the clustering of all thumbwheels is not practical. See Figure 7-6.

The control and display components were selected on the basis of permissibility, readability and operability, compatability with related systems and typical cost, scheduling, reliability factors. Permissibility, to meet the requirements of CFR title 30, can not be accomplished on a component by component basis since environmental hazards are concerned also with total power usage, layout of wire harnesses and multiple failure safety factors. In practice, the avoidance of human error is a major concern and the methods of providing information to the operator in useable form is the chief tool in error reduction. After determining what information is needed, component specification is aimed at finding the lowest power consumption method of reliably and economically providing information.

Component layout is reflected in the Master Control Station console drawing, Figure 7-7. The console houses an accessible card system. Connectors and panel space allocation allow a 30% growth capability.

The shearer control panel is used in the manual mode and can be enabled by the master control panel mode select or by mode selec-

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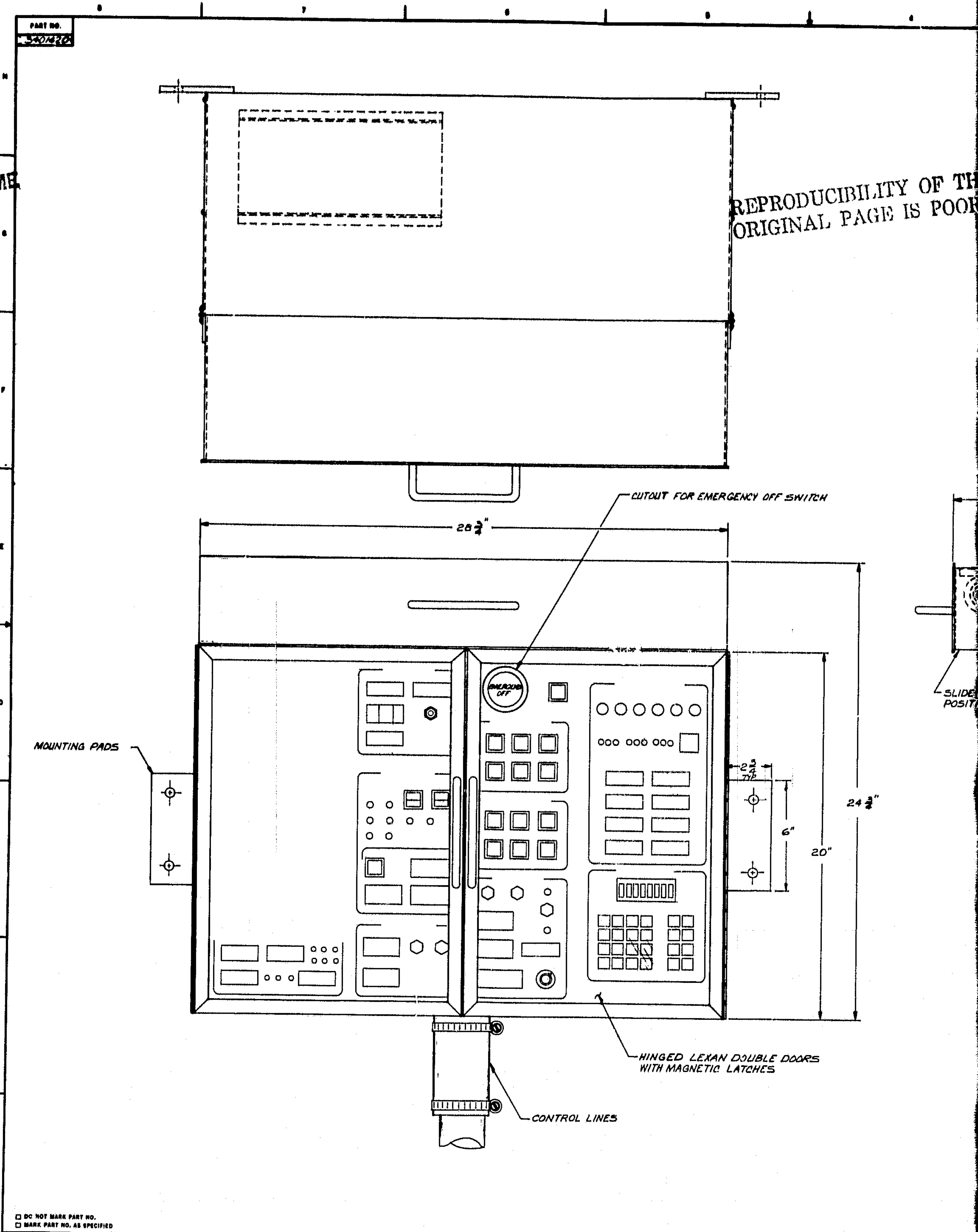

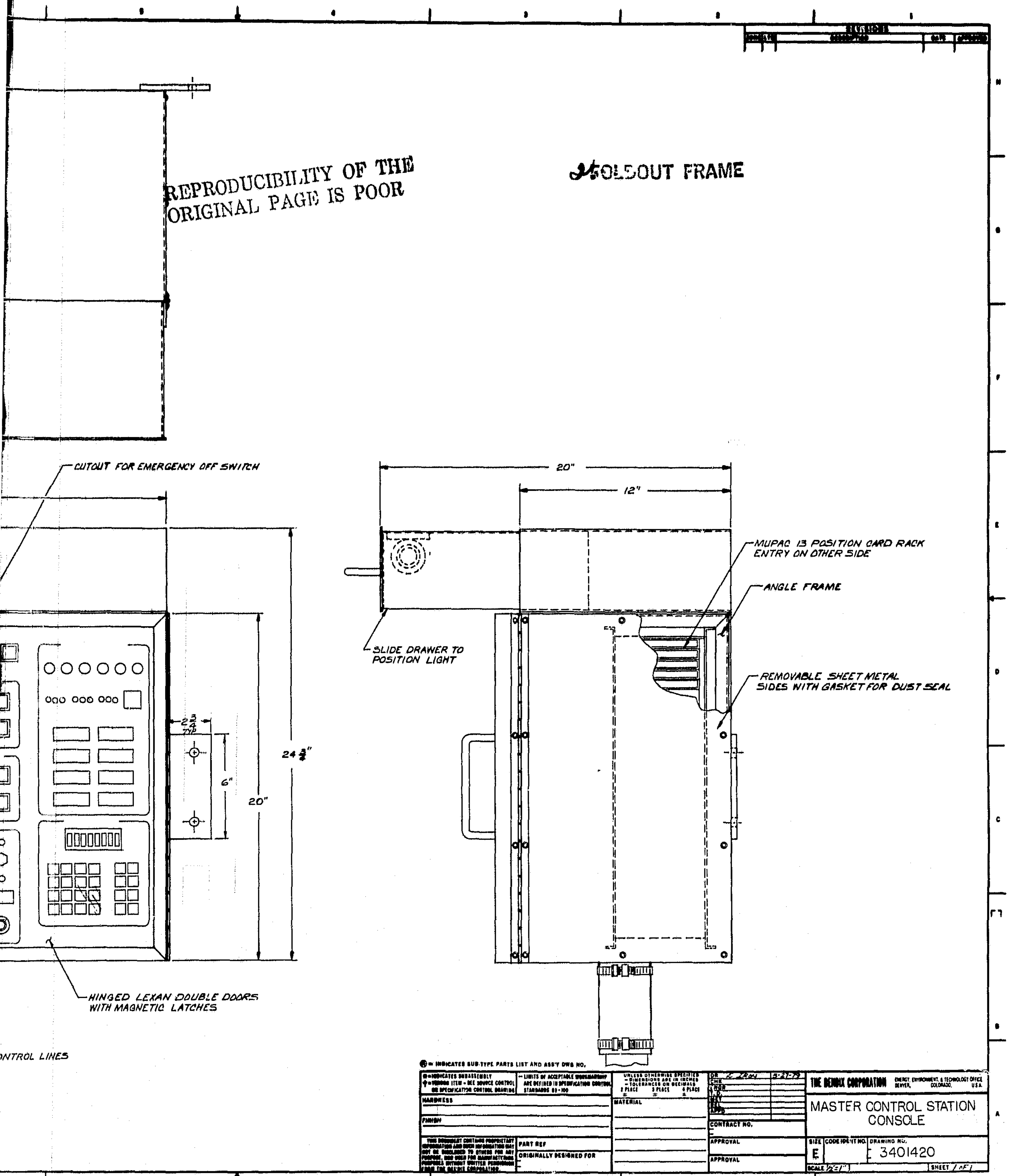
CUTOUT FOR EMERGENCY OFF SWITCH
20"
12"
MUPAC 13 POSITION CARD RACK
ENTRY ON OTHER SIDE
ANGLE FRAME
SLIDE DRAWER TO
POSITION LIGHT
REMOVABLE SHEET METAL
SIDES WITH GASKET FOR DUST SEAL
2 3/4 TYP
6"
24 3/4"
20"
HINGED LEXAN DOUBLE DOORS
WITH MAGNETIC LATCHES
HARDNESS
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Figure 7-7

tion on the shearer control panel or by key removal from the safety switch when a man enters the face area. Once in this mode, the mode can not be changed if the shearer control panel is placed in manual command or if any shearer panel controls are not in the "off" position.

The controls are all dedicated controls and the displays supplement visual information. Further information will be provided by the voice link to the master control station.

The Electronic Control Module (ECM) requires a control panel for callibration purposes. This is provided by the master control panel in end to end calibration and checkout. If trouble shooting requires insertion at the module, a panel is provided. The shearer control panel is shown in Figure 7-8. The ECM and its associated control panel is discussed in Section 4.

7.3 Description of Master Control Station (MCS) - The Master Control Station (MCS) provides the following major functions to the system:

1) Discrete Data Display
2) DAS Data Display
3) Discrete Operational Control
4) DAS Operational Control
5) Fail Safe Monitors
6) Error/Malfunction Processing

The MCS contains a communication link for communications with the shearer and with the roof supports. In the normal course of events communications messages, in preformatted form, are transmitted and received by the MCS communications link via subcarrier wire-line.

The Master Control Station operates under the control of the MCS Monitor (BOSS). This monitor controls the execution of a number of software routines involved in operation, it provides for passing data from one subroutine to the next for purposes of display and con-

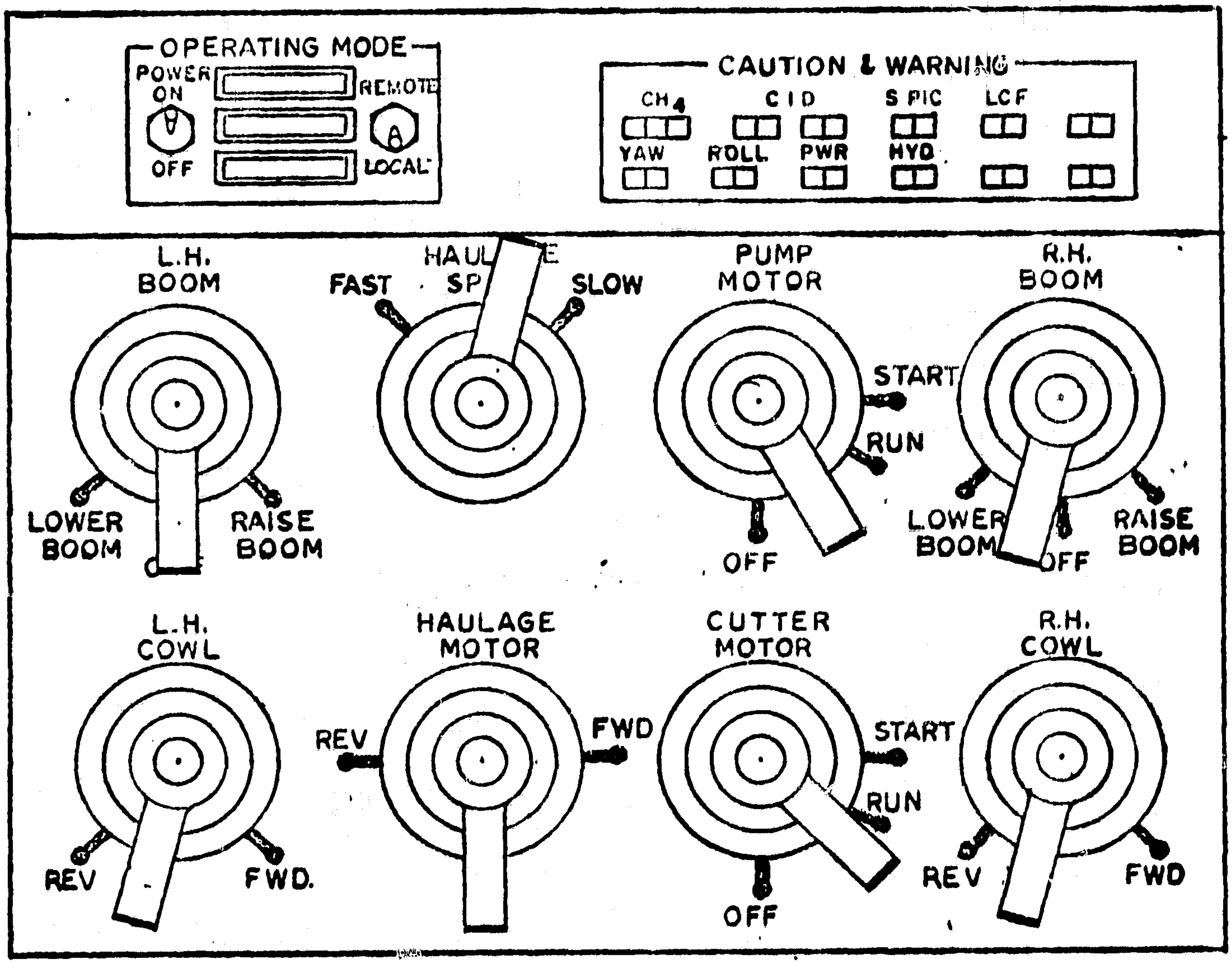


Figure 7-8. Shearer Control Panel

trol, and it provides for initializing of the system and for error detection. The subroutine (FRSUP) provides the capability of presenting data to the displays and of reading certain of the command inputs from the pushbutton control panel. Those command inputs that are normally available to the operator independent of the operational mode are:

- PARAMETRIC DATA INPUTS
- MODE INPUTS
- HAULAGE RATE
- FIRE SYSTEM
- EMERGENCY OFF

In order to operate other controls available on the MCS it is necessary to insert a key in the keyswitch provided. This key will allow operator access to all of the discrete pushbutton controls and to the DAS keyboard. Use of the keyswitch will force the system out of the automatic mode, if it is in the automatic mode, and force it to the remote mode. Another type of keyswitch exists in the system distinct from this one on the C&D panel. These are the keyswitches located on the first and last of the roof supports, i.e., roof support nearest to the headgate and tailgate respectively. In order for either remote or automatic operation to take place all of the keys required must be inserted into these keyswitch panels. The removal of any one of these keys will instantly force the system to go to the manual mode of operation from whatever pre-existing mode it was in. This is a safety measure to preclude the likelihood of inadvertent automatic or remote operation with a man on the face. It is expected that the final safeguard in this matter is procedural; i.e., a man going down on the face must remove his key from the roof support.

During normal automatic operation the Yaw Control System (YCS) keeps track of the positions and recent previous history of face conveyor sections and roof supports. In the event that the system is

taken out of the automatic mode the YCS must assume, for safe operation, that it no longer knows the current position of face conveyor sections and roof supports. This is so because they could have been moved in such a way as to circumvent the YCS monitor. Under the circumstances the YCS, when it is returned to automatic, will illuminate the "CALIBRATE" indicator to request a calibration pass along the face. This calibration pass will restore current position data to the YCS. If the operator knows that the roof supports have not been moved he may so inform the YCS via the DAS panel. The YCS will then assume that the data it has in memory is current and accurate. In the event of a power failure the first pass along the face must be a calibration pass when automatic Yaw control is desired.

The parametric data inputs on the MCS are data inputs, for configuration control and calibration, that serve as microcontrols for system operation. These parameters are:

- CID Parameters (5)
- Head Coal (1)
- Bottom Coal (1)
- Seam Thickness (1)
- Successive Cut Difference (1)
- Pick Sensitivity (1)
- Seam Inclination (1)
- Straightness (1)
- Criteria (1)
- Headgate Correction (1)
- Tailgate Correction (1)

The CID parameters must be inserted via the digit switches provided through the front panel. This data consists of five numbers in signed exponential notation. The numbers represent the calibration constants required for proper operation of the coal interface detector (CID).

The head coal, bottom coal, seam thickness, and successive cut difference are parameters that are required for proper operation of the shear drum control system. Pick sensitivity is a calibration constant required to set the sensitivity of the senitized pick detectors. The seam inclination is a parameter which allows the roll control system to be operated so as to cause the shearer to follow a seam.

The straightness, criteria, headgate and tailgate correction data are inputs to the YCS. The YCS is designed to use a combination of partial periodic straightening. The straightness is the parameter that defines how straight to make the face conveyor when it is straightened. The criteria is the parameter which determines when the face conveyor will be straightened. The two correction parameters for headgate and tailgate provide the base line reference to the survey stake for the YAW system.

In normal system operation the control panel microprocessor must deal with three sources of potential error or malfunction. These are:

1) Malfunction Flags
2) Discrete Control Operator Error
3) DAS Control Operator Error

A malfunction flag is transmitted to the MCS from the roof supports or from the shearer. This flag is used by the MCS to cause the associated discrete display to blink on and off at a 2 pps rate to alert the operator. In the event that no discrete display is associated with the malfunction the hold light will be caused to blink at a 2 pps rate and the address of the data word that describes the malfunction will appear on the DAS display. If an over-ride is permitted for the malfunction indicated it may be written into the system via the DAS keyboard.

In the event the operator makes an error in a discrete command entry the associated button will blink at a 2 pps rate and the starting address of the conflict table entry will be displayed on the DAS display. By calling up and reading that section of the conflict table the operator error, if not already understood, may be determined.

In the event that the operator makes a DAS error while entering data or command via the DAS keyboard the DAS keyboard will be caused to blink at a 2 pps rate and the erroneous entry will be prevented from getting into the system.

Mode changes when introduced into the system must conform to the following set of constraints.

1) A system operating in automatic may not be placed in remote without an MCS key; it is forced to remote by the operation of such key.

2) A system operating in automatic will be forced to the manual mode if a roof support key is removed or if any manual button in the system is operated.

3) The power up or default mode is the manual mode.

In the normal operation of the MCS the system will monitor the status of automatic, remote or manual operation. In the event of a malfunction or hold occurring in the normal sequence of events the malfunction error or hold will be displayed and the operator, with key access, may interrogate the system to obtain data on the nature of the malfunction or hold. When the MCS is operated with a keyswitch, operator intervention in the activity of the machine does occur. As this intervention occurs, each operator command is tested against a conflict table, where possible, so as to preclude illegitimate operational sequences from causing damage. In the event the operator makes an error in the operation of the discrete buttons or the DAS command inputs, the malfunction error CODE will be caused to blink on the DAS display. The system will not otherwise accept or act on the error.

7.3.1 Remote Operation - When operating in the remote mode of operation, with key in C&D panel keyswitch, all of the buttons and controls are available to the operator to remotely control the system. Discrete command buttons are provided for discrete control of the shearer as shown on the C&D panel, Figure 7-2. Remote control of the roof supports may be accomplished through the DAS panel by selecting its address and writing micro-control words into its ram memory. The remote mode of operation for the roof supports is provided only for checkout; it is not expected that this mode of operation will provide useful roof support system control although it will provide for full remote operational control of each individual unit.

7.3.2 Digital Address Subsystem (DAS) - The display address subsystem (DAS) is a means available to the MCS operator to intercommunicate with the operating system. A number of fixed operating algorithms are included for the purpose of facilitating communications, minimizing error generation, and dealing with the errors that are generated in the system.

All access modes on the DAS are activated by the same keyswitch that allows access to the discrete pushbutton control. The display modes on the DAS are independent of the keyswitch and will operate to display certain classes of data without keyswitch actuation. When the keyswitch is activated, additional private display data may be called up by the operator.

The basic pushbutton controlled operational modes of the DAS panel are as follows:

READ	EDIT	CALIBRATE
WRITE	HALT	
PRINT	CLEAR	

All data entered into the system through the keyboard will be in hexadecimal format. Data read out on display will be in hexadecimal. The operator may introduce an absolute memory address into the system

via the DAS keyboard. As the address is entered it will appear on the DAS display. After the address is keyed in, the operator button associated with it (READ-WRITE-EDIT-etc) is depressed to cause the requested operation to occur.

The address field of the DAS is such as to allow the addressing of 255 unique devices each of which may have up to 65K (65,535) of eight bit memory locations. The address may be entered by keying in two hexadecimal digits for "device" followed by four hexadecimal digits for "address." The digits will appear on the display as they are keyed into the panel. After they are displayed data may be keyed into the panel in a similar manner where it will be displayed as two digits in hexadecimal.

After keying in the address and/or data the execute command, when operated, will cause the desired operation to take place. The execute commands are entered by depressing one or more of the DAS pushbuttons. These pushbuttons operate as described below.

7.3.2.1 READ - After keying in the device and address as described above, the operator may cause to be displayed in the data area of the DAS display the data currently stored at that memory location by depressing the "READ" button. Note that for a read operation only the address need be keyed into the system; the two data characters for the data section of the display will be accessed and displayed by internal logic. In the event that more than one sequential address is to be read the operator may depress the "EDIT" button. When the "EDIT" button is depressed immediately after the address is entered the system interprets the address as a starting address. Thereafter it will present the data associated with the displayed address when the "READ" button is depressed. For each subsequent operation of the "READ" button the display will present the next contiguous absolute address and the data associated with it. It will not respond to jumps, exits or calls in order to follow the course of an executing program.

For purposes of determining absolute address fields the "device number" will not be considered as a part of the address. Thus memory wrap around, when it occurs, is limited to a single device only.

7.3.2.2 WRITE - After keying in the device and address as described above, the operator may write into the memory address displayed if the address does not fall within a memory region protected by a write lock. To write in the memory address displayed it is necessary to key in the two characters of hexadecimal data to be written and then depress the "WRITE" button. If the address is unprotected by a write lock the data will be written. If the address is protected by a write lock the display will blink at a 2 pps rate, approximately, and the data will not be written. An operator error flag will be stored and the operator may display the particular error flag by depressing the "ERROR" button.

In the event the operator wishes to write into two or more successive memory locations he may simplify the task by use of the "EDIT" button. When the "EDIT" button is depressed immediately after the address is displayed, the MCS will interpret the address as a starting address. Thereafter only the data to be written need be keyed in. For each subsequent depression of the "WRITE" button the MCS will write the displayed data into the displayed location, advance the displayed address to the next contiguous absolute address, clear the data field and await a new data entry and another operation of the "WRITE" button.

7.3.2.3 EDIT - In the "EDIT" mode of operation the operator may sequentially read into or out of a series of memory locations beginning with the starting location keyed in and entered in the usual way. After keying in the starting location the operator depresses the "EDIT" button. After the "EDIT" button is depressed each subsequent operation of the "READ" button will cause the address to be incremented by one and the data in the incremented location to be

displayed. In the event that it is desired to use the "WRITE" operation in the "EDIT" mode the operation is similar. First the address is entered in the normal manner then the "EDIT" button is depressed. The "WRITE" data is then entered in the usual way. For each subsequent depression of the "WRITE" button the data is entered, the data display is cleared, the address is incremented by one and a subsequent data word may be entered by sequentially keying it in and operating the "WRITE" button.

7.3.2.4 RECORD - During the operational debugging phase of the test of the shearer it will be necessary to have access to large area printouts of memory contents, dumps. The diagnostic methods to be employed for this purpose make it necessary to be able to study program behavior with these memory dumps. For this reason the print routine is included. The MCS contains a connector to which a small portable cassette tape may be connected.

When the cassette tape is connected a memory dump may be initiated in the following way. The address of the first memory location to be printed is entered and the "PRINT" button is depressed. The system will accept this as a starting address and then clear the display. The address of the last memory location to be printed out is then keyed into the system where it is displayed. The "PRINT" button may then be depressed a second time. The system will then record and display the memory area requested together with absolute address of the memory location that contains each recorded data word and then halt after recording the last line required.

In the event no ending address is entered before the "RECORD" button is depressed for the second time the print will cause "memory wrap around" to occur and the entire contents of memory will be printed with the last word printed being that word which occupies the location that immediately precedes the first location printed. No page formatting of the data is included and no "low paper" or other sequences are included. It is the responsibility of the operator to assure that a functional printer, with paper ready to go is available before a print out is requested by the "PRINT" button.

7.3.2.5 CALIBRATE - The CALIBRATE button is reserved for the case where the operator of the MCS panel desires to calculate new constants for the CID. When new CID constants are to be calculated the operator must first WRITE into special reserved locations in memory the measured coal values and the CID counts associated with those values. Then the operator depresses the CALIB button to inititiate the calculation. After the calculation is complete the DAS display will illuminate the end code and the operator may now access the results. To obtain the results it is necessary to depress the EDIT button and then the READ button. For each operation of the READ button two characters of the desired data will appear. As the data is read from the DAS it may be immediately entered into the parametric digit switches on the MCS reserved for the purpose.

7.3.2.6 HALT - When the "HALT" button is depressed an ongoing record operation will stop at the memory location displayed when the "HALT" button is depressed. The record may be continued by again depressing the "PRINT" button.

7.3.2.7 CLEAR - When the clear button is depressed data, address and device information is removed from the display. In the event an operator makes an error while entering from the keyboard it may be corrected by depressing "CLEAR" and then keying in the correct entry. In the event a display exists because of system rather than operator action it may also be cleared from the display with the clear button.

7.3.2.8 READY - The "READY" mode of operation is entered by keyswitch. It is simply a mode of operation where the DAS keyboard is responsive to input operations. The display is available to display operator error even when the keyboard is not in the "READY" mode.

7.3.3 Malfunction and Error Processing - In all modes of operation the system acts to monitor key operational parameters for malfunction potential and to monitor operator control commands so as to minimize the potentially catastrophic effect of conflicting operator inputs.

On the shearer, as on the roof supports, instrumentation is provided to enable the remote display of equipment malfunction. A list of typical malfunctions to be instrumented on the shear is shown in Table 7-4. Most of these malfunctions do not have a discrete dedicated display. When they occur in the system - the system will typically go into a hold mode, blink the "hold" indicator and display the error code on the DAS display panel so that the operator may intelligently intervene. Some of the malfunctions, whose potential consequences are not adjudged to be catastrophic, have an over-ride request associated with them. In the event that the operator sends the over-ride for one of these malfunctions the system will accept the over-ride command, go out of the "HOLD" mode and continue to sequence through its subroutine. The over-ride command must be entered through the DAS panel by an operator who has key access before the timeout associated with the over-ride expires. Should the over-ride not be delivered in time by the operator the system will power down the shear. Operation may be restarted from the sequence start point by again depressing the "POWER ON" button.

In the event that an instrumented malfunction of the roof supports occurs when the shearer is in motion the shearer will automatically receive a stop haulage motor command, the hold indicator will be illuminated, the roof support malfunction indicator will be illuminated. If a discrete indicator does not exist for the particular malfunction the error code will be presented on the DAS display so that the operator may intelligently intervene. A list of typical malfunctions that can be identified from roof support instrumentation is as shown in Table 7-5.

In addition to malfunctions caused by equipment - environment interactions, an additional class of potential problem due to operator error must be considered. In any complex man-machine interface the system must be capable of guarding itself against inadvertent or accidental command conflicts that may be introduced in real time into

Table 7-4. Shear Malfunction Table

	OVER-RIDE	SHEARER HALT
FIRE SUPPRESSION SYSTEM	X	
LEADING LCF DEPLOYED	X	
LEADING PCF STOWED	X	
LEADING CID DEPLOYED	X	
TRAILING LCF STOWED	X	
TRAILING PCF DEPLOYED	X	
TRAILING CID STOWED	X	
CID POWER FAILURE	X	
CID POWER FAILURE		X
FACE CONVEYOR MOTOR HEADGATE		X
FACE CONVEYOR MOTOR TAILGATE		X
PANEL CONVEYOR MOTOR		X
LEFT STAGE LOADER MOTOR		X
RIGHT STAGE LOADER MOTOR		X
COMMANDED DIRECTION VALID		X
SENSITIZED PICK DATA INVALID		X
INVALID LEAD DRUM SENSITIZED PICK SETTING		X
LEAD DRUM RANGING ARM POSITION ERROR		X
LCF VALID		X
LEAD DRUM SENSITIZED PICK OUTPUT INVALID		X
SENSITIZED PICK SETTING INVALID		X
INVALID TOP COAL THICKNESS SETTING		X
INVALID CID READING		X
LEAD DRUM RELATIVE POSITION ERROR		X
INVALID HEAD THICKNESS SETTING		X
NEGATIVE LEAD DRUM COMMAND		X
TRAILING DRUM INVALID POSITION		X
INVALID SEAM THICKNESS SETTING		X
INVALID TRAILING DRUM SENSITIZED PICK DATA		X
LAST CUT FOLLOWER CONTACT		X
PRESENT CUT FOLLOWER CONTACT		X
CID CONTACT		X
LCF WORD NOT VALID		X
PCF WORD INVALID		X
SENSITIZED PICK CARRIER ERROR		X
WATER FLOW NOT ADEQUATE		X
RIGHT COWL POSITION ERROR		X
LEFT COWL POSITION ERROR		X
SHEARER HYDRAULIC PRESSURE OUT OF TOLERANCE		X
SUCCESSIVE CUT VALUE NOT ENTERED		X
SEAM HEIGHT NOT ENTERED		X
CUT HEIGHT NOT ENTERED		X
BOTTOM DRUM CONTROL HEIGHT NOT ENTERED		X

Table 7-5. Typical Roof Support Malfunctions

MALFUNCTION	DISCRETE DISPLAY	SHEAR HALT
ROOF LOAD OUT OF LIMIT	X	
FAIL TO POSITION	X	X
ECHO CHECK FAIL	X	
POWER LINE FAULT	X	
HYDRAULIC PRESSURE LIMIT	X	
BREAK LINE FORWARD	X	
CALIBRATION REQUEST	X	
VERTICAL RAM POSITION		
HORIZONTAL RAM POSITION		

an operating system. All discrete pushbutton sequences are checked against a conflict table in one of the MCS subroutines. The conflict table update is carried on as a normal part of MCS software operation. When such a conflict in command inputs is encountered the system will blink the last conflicting command entered and then display the starting address of the appropriate section of the conflict table so that the operator may investigate the problem. All command input addresses to the DAS keyboard are checked to determine if an attempted write lock violation exists. If it does the display erases and the write lock violation error code is blinked on the DAS display. Certain other key parameters such as direction of travel, deployment of sensors and snake condition of the face conveyor are monitored in a state table which will disallow any DAS command entries that would cause a catastrophic system conflict. Because of the great degree of control flexibility inherent in the DAS keyboard control, it is not practical to create a state table sufficiently large to preclude all erroneous operator intervention. In the event that one of the tested conflicts does occur the DAS system will inhibit the execution of the command, display the error code for the condition and then blink the DAS display to attract operator intervention.

7.3.4 System Operation - The software routines used to implement the operation of the MCS operate in a dedicated microprocessor under control of the MCS software monitor "BOSS". These routines are as follows:

BOSS	System Monitor
FRSUP	Refreshes the display and transmit files periodically.
START	Initializes system during turn-on
GETIT	Error checks received data
ERRIT	Processes errors and malfunctions for display or transmission

SENIT	Processes transmit data
REMOT	Processes discrete commands for transmission
DASGO	Operates the DAS keyboard and display

These routines are resident in programmable read only memory (PROM) on the microprocessor data bus in the MCS.

7.3.4.1 BOSS, Figure 7-9 - This subroutine is the master monitor for the MCS. Its task is to monitor and supervise the activity of the subprograms that run under it. It will cause the orderly transfer from one subroutine to another, it will operate the error routine, it will maintain the system files and it will, in general, take care of all supervisory, housekeeping and filing tasks required by the executing subroutines.

7.3.4.2 FRSUP, Figure 7-10 - The subroutine FRSUP is the basic manipulation routine in the MCS. It performs all of the routine refresh functions that are not mode dependent. Periodically it refreshes all of the data displayed on all of the discrete data displays. It formats the data presentation on the DAS display. It displays, and blinks when necessary, all of the DAS display data. It displays, and blinks, the hold button and stores malfunction data in the DAS malfunction file. It performs the code conversions required, i.e., BCD - HEX - BCD. Reads all parametric data inputs and formats it for transmission to the shear or to the roof supports. It calculates bottom coal thickness. It operates the audio alarm. It reads the non-key discrete inputs. It displays the malfunction data. Data that is passed to the FRSUP routine can be assumed to be error free because of prior polynomial comparison in the GETIT routine. The data that FRSUP outputs is passed to the SENIT program for transmission to the shear or roof supports.

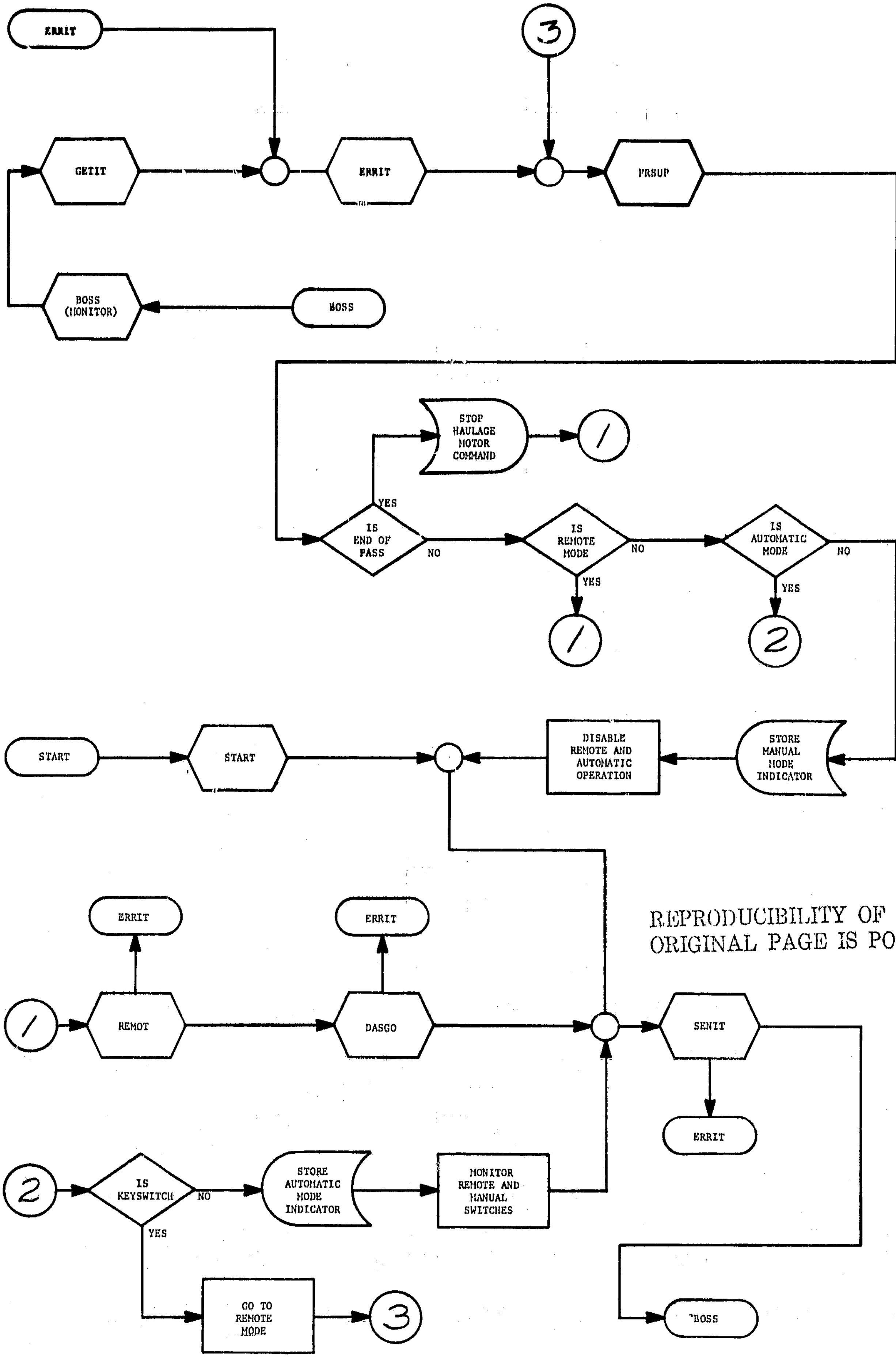
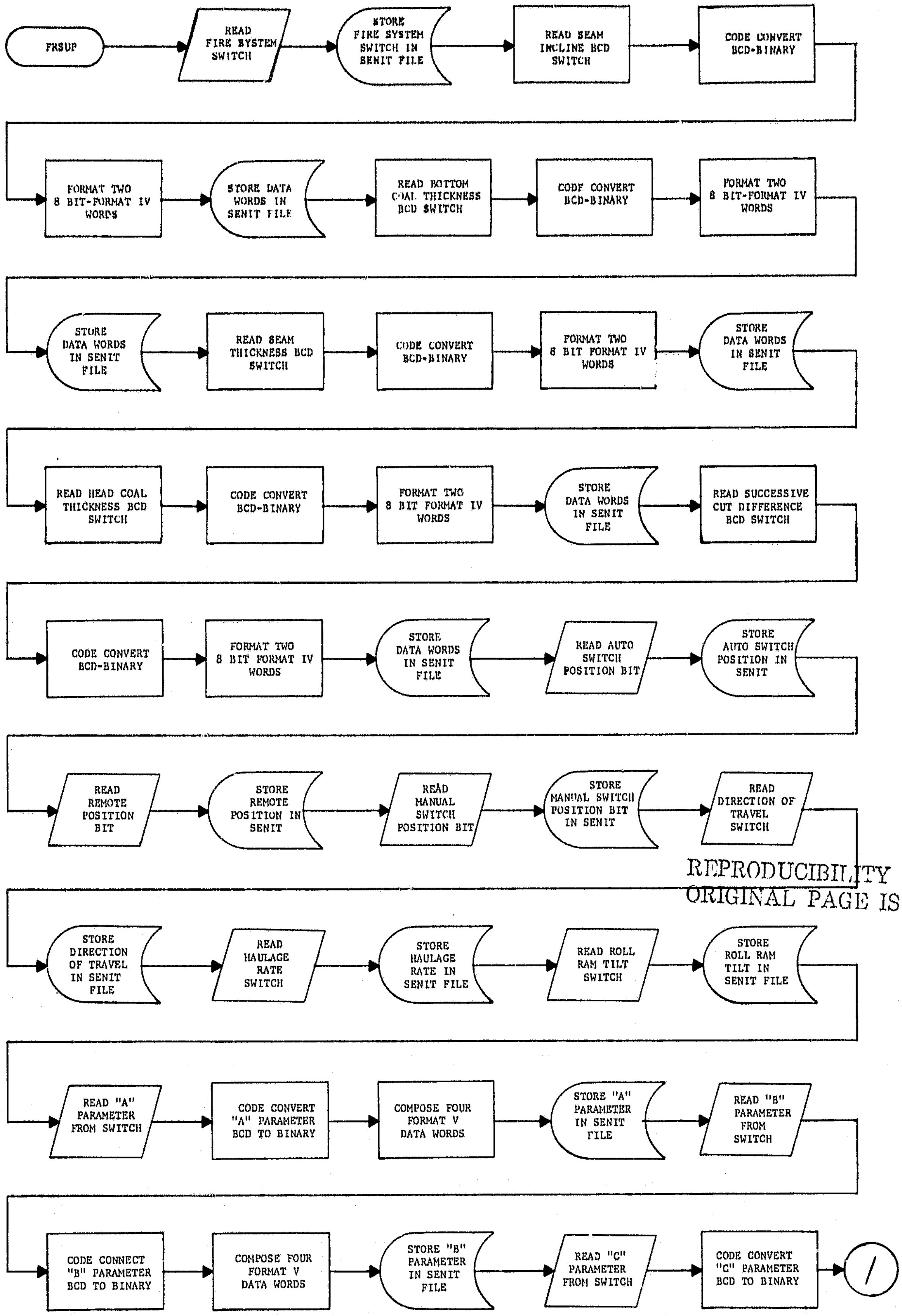


Figure 7-9. System Software Monitor (BOSS)



FORMAT I	DATA	SINGLE BIT INDICATORS
FORMAT II	DATA	BCD DATA
FORMAT III	DATA	HEX DATA
FORMAT IV	DATA	BINARY OBJECT FROM BCD SOURCE
FORMAT V	DATA	FLOATING POINT

Figure 7-10. Display Refresh Software Routine (FRSUP) (Page 1 of 8)

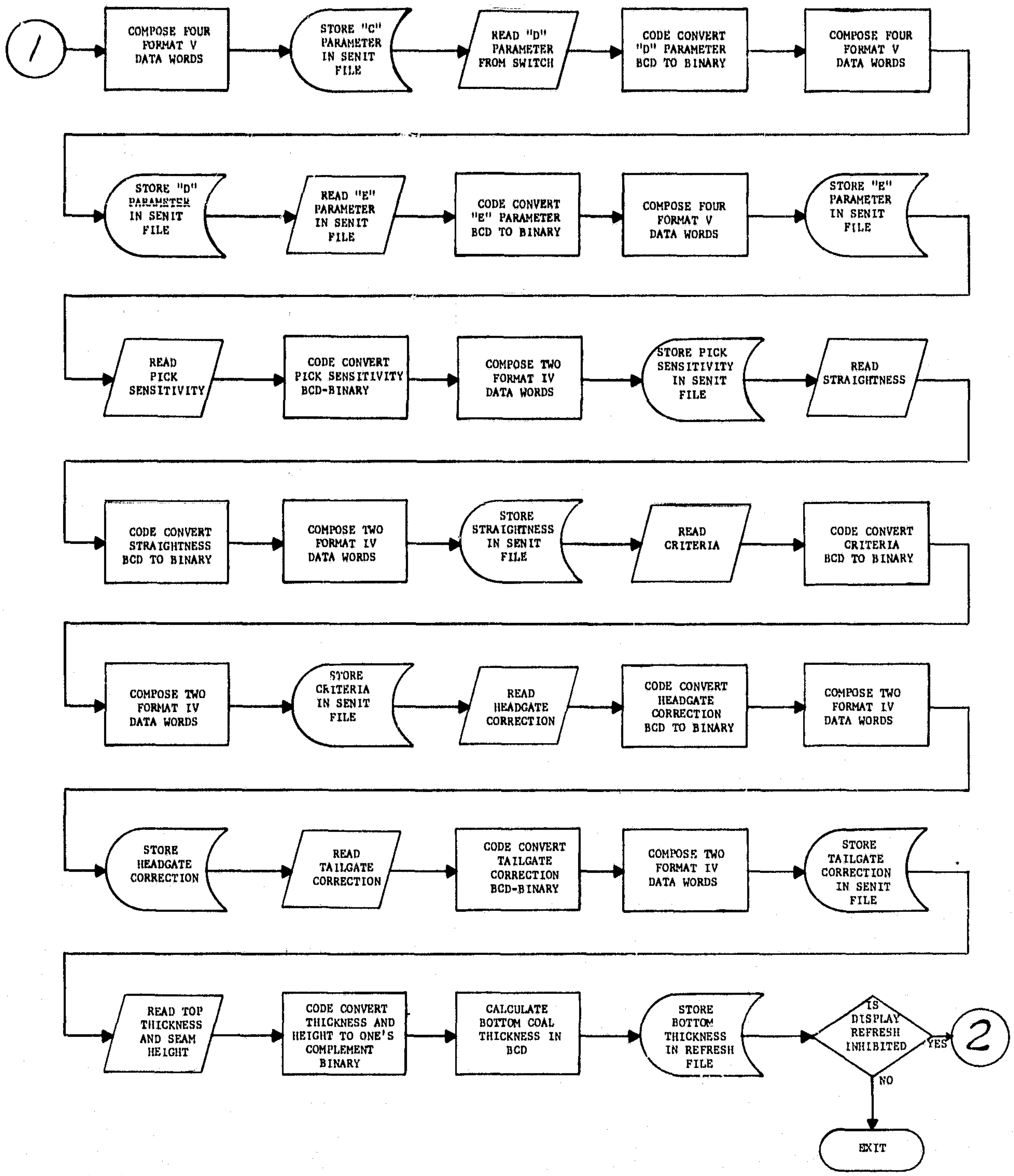


Figure 7-10. Display Refresh Software Routine (FRSUP) (Page 2 of 8)

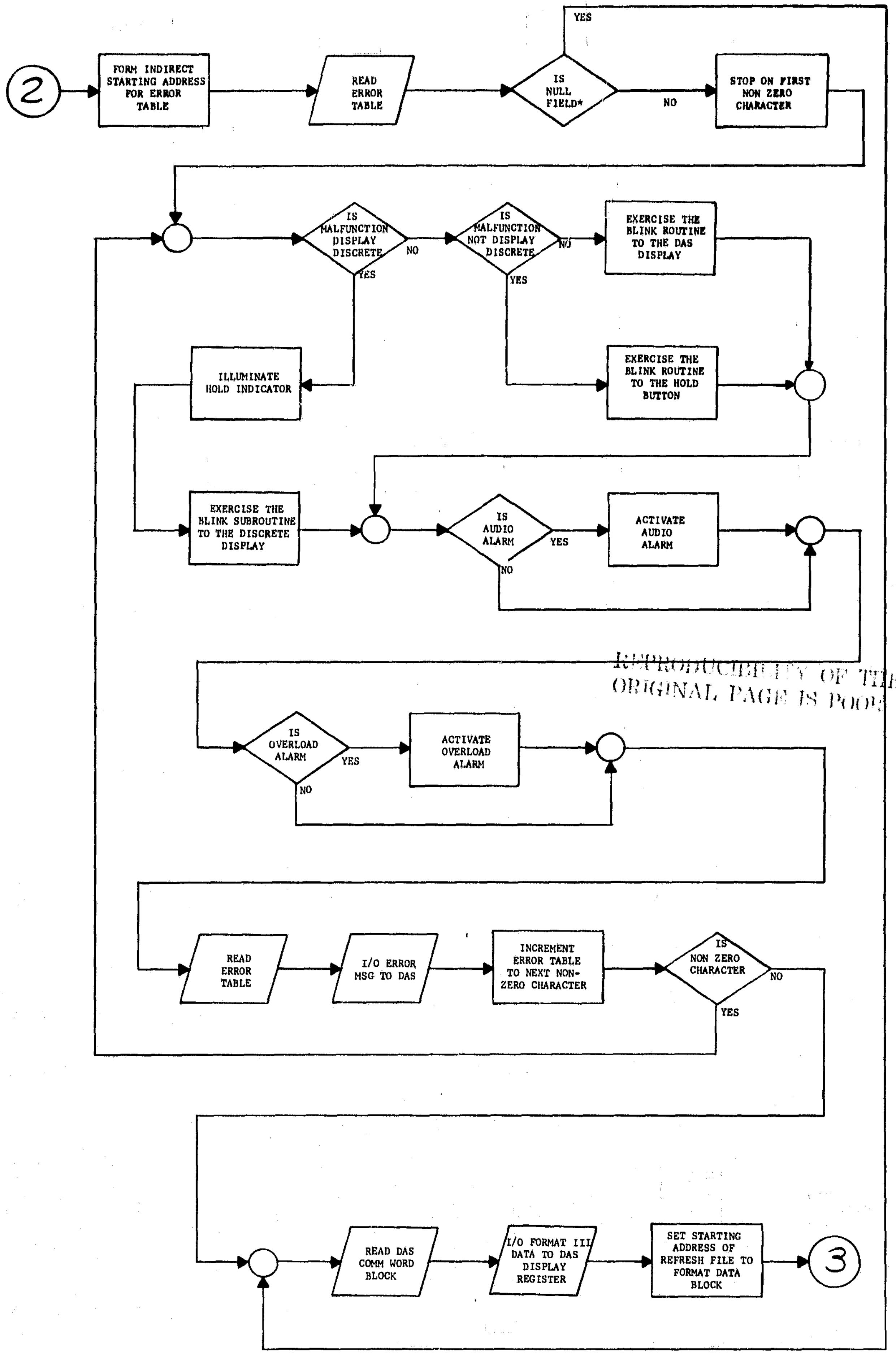


Figure 7-10. Display Refresh Software Routine (FRSUP) (Page 3 of 8)

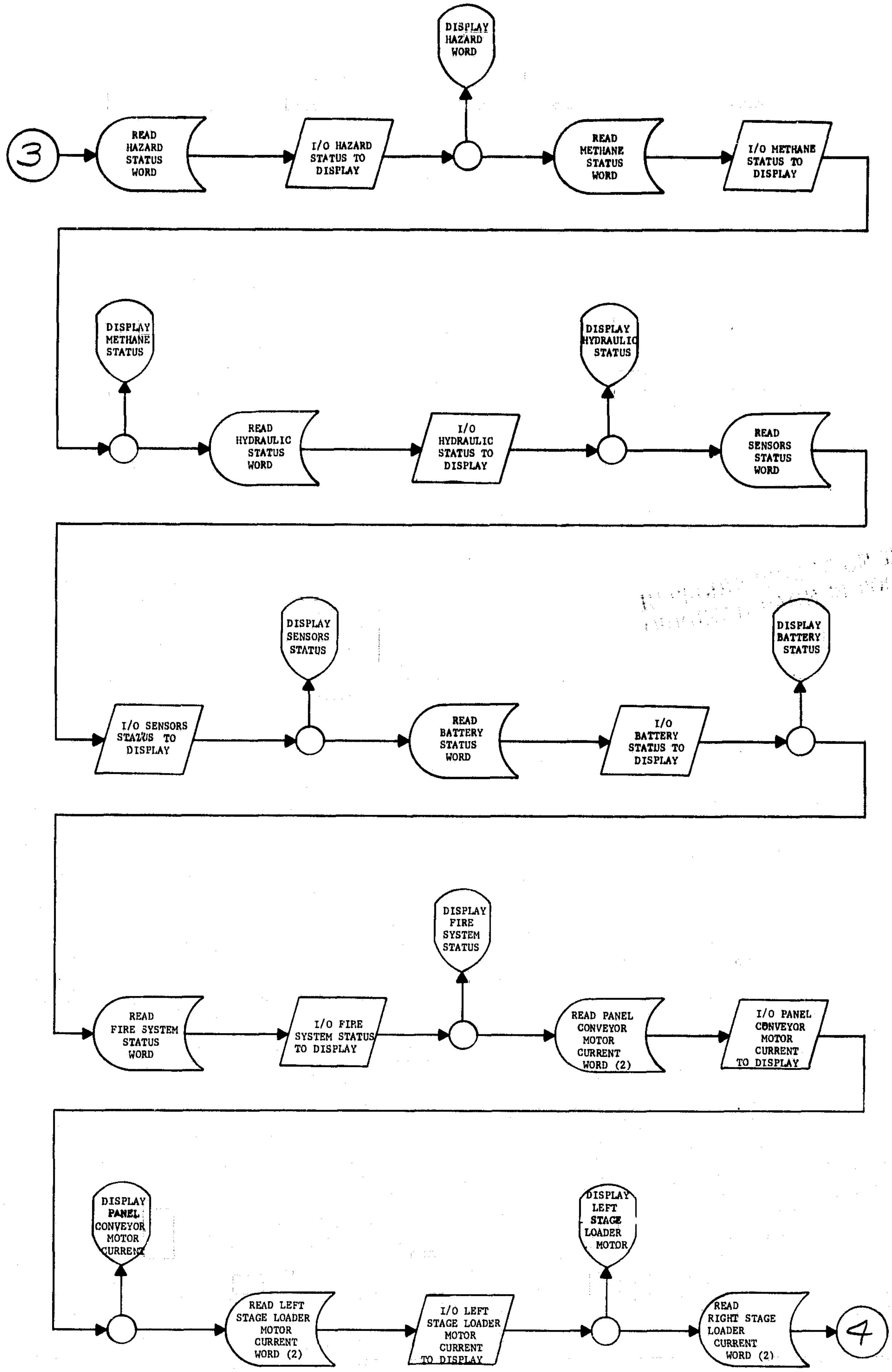


Figure 7-10. Display Refresh Software Routine (FRSUP) (Page 4 of 8)

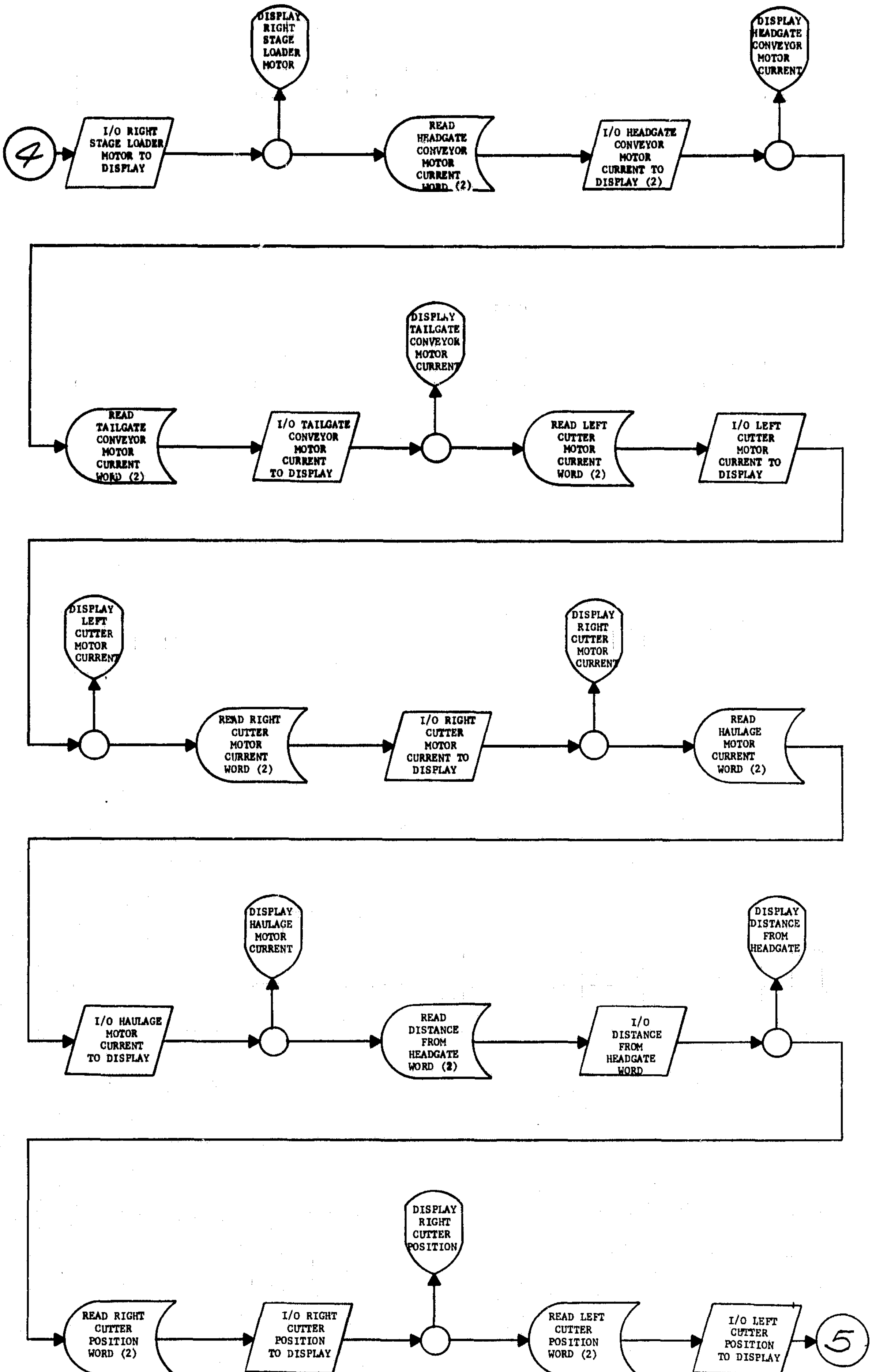


Figure 7-10. Display Refresh Software Routine (FRSUP) (Page 5 of 8)

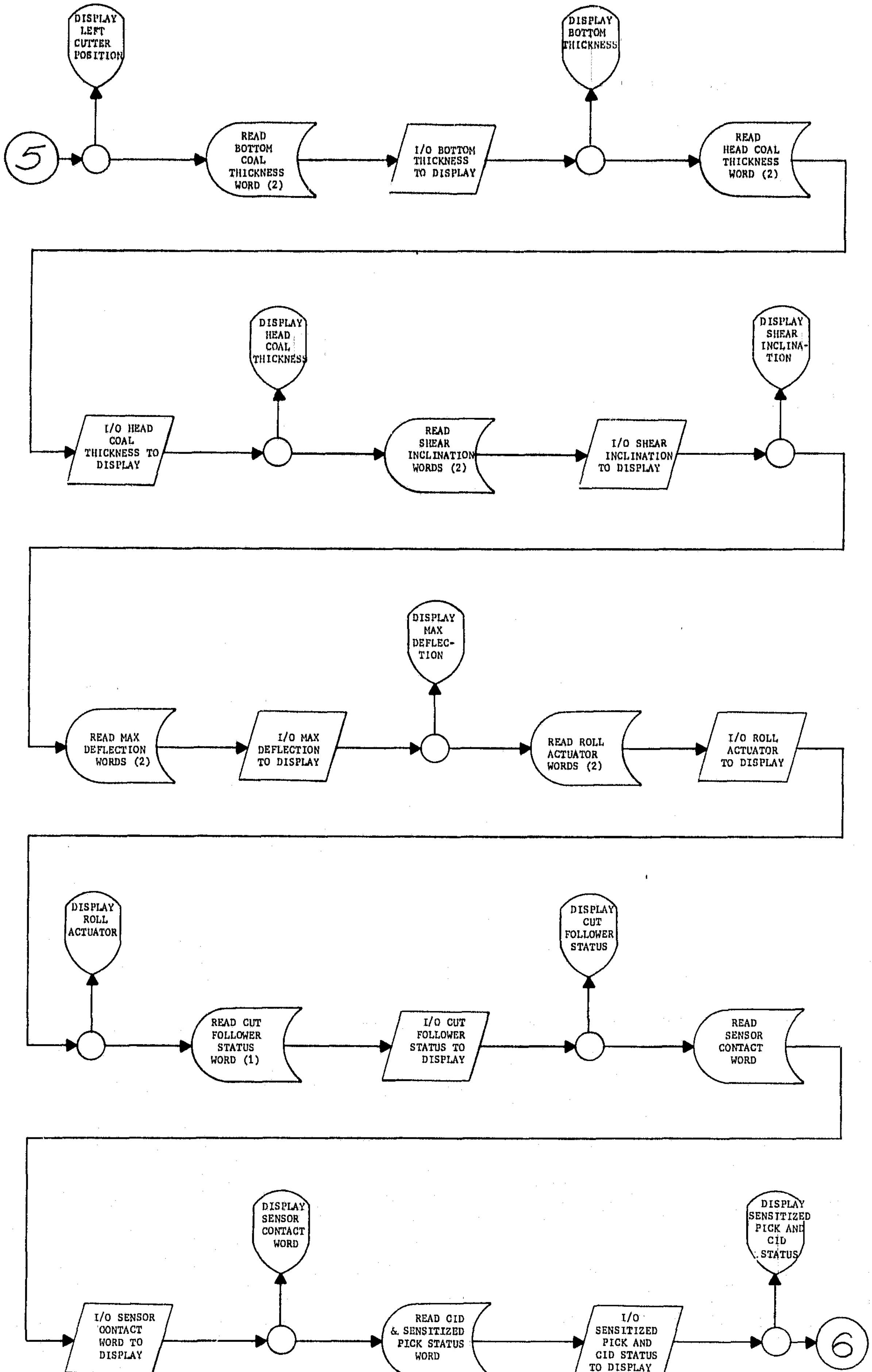


Figure 7-10. Display Refresh Software Routine (FRSUP) (Page 6 of 8)

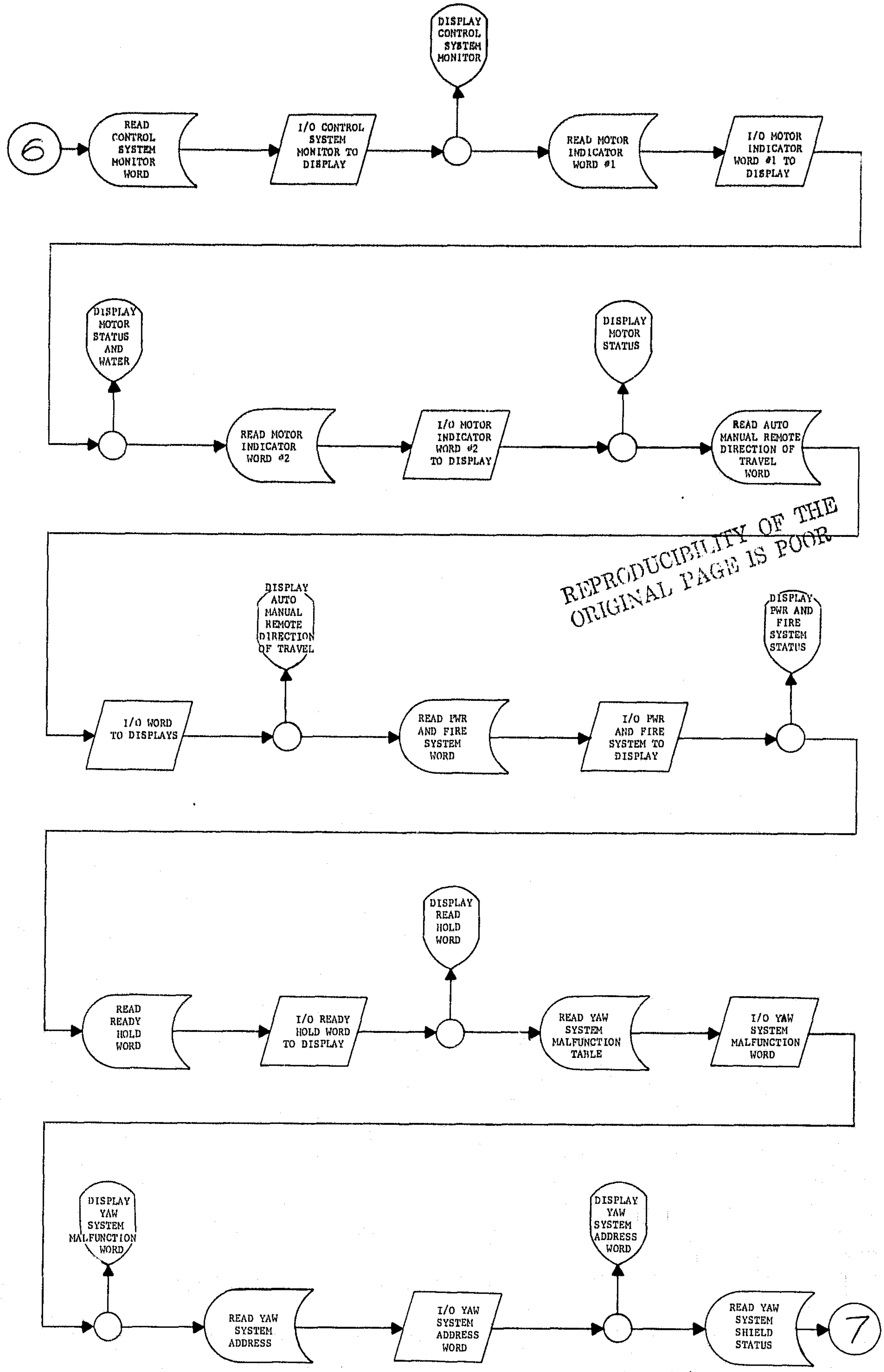


Figure 7-10. Display Refresh Software Routine (FRSUP) (Page 7 of 8)

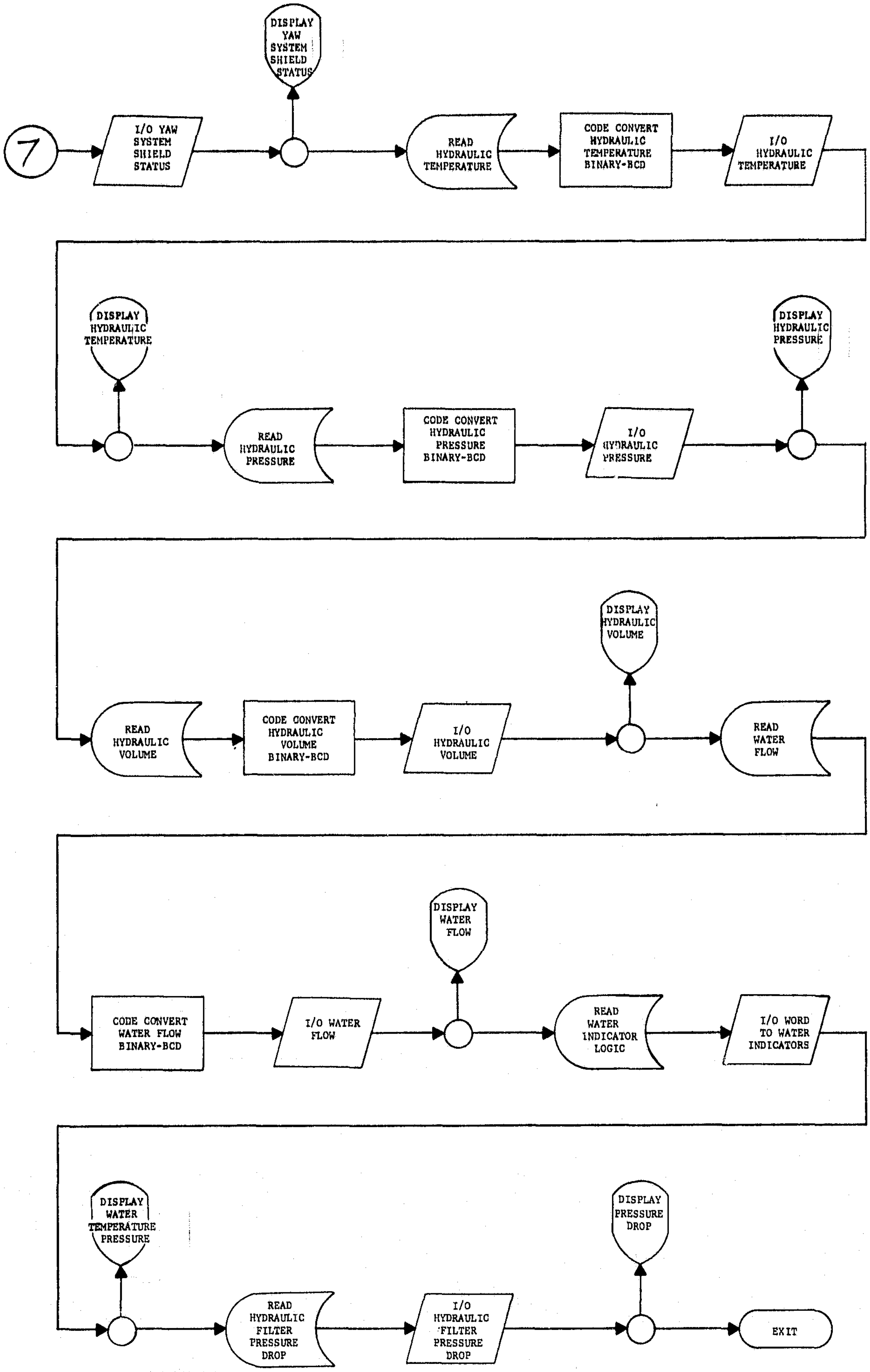


Figure 7-10. Display Refresh Software Routine (FRSUP) (Page 8 of 8)

7.3.4.3 START, Figure 7-11 - When the system is initially turned on a small subroutine will automatically initialize the system. The operation is as follows. When the power is initially turned on, the microprocessor receives a reset pulse, from a hard wired turn on circuit, approximately 10 Ms in length. During this reset pulse the system clock is suppressed, registers 1, NQ are reset and the system is placed in S1 state. Upon the release of the reset pulse the clock starts and the microprocessor executes a built in register, stack, address, interrupt and flag initialization routine. At the conclusion of this step the microprocessor executes a ROM based system initialization routine. This routine clears all displays to zero, reads the parametric data from thumbwheel switches, stores the output data to the system in the SENIT file, stores commands to shearer and roof supports to initialize their subsystems in the SENIT file and then turns over control to the system monitor.

7.3.4.4 GETIT, Figure 7-12 - The GETIT program is used to error check and to format the data that it finds in the raw data receive block from the communications receive block. GETIT will develop a check sum polynomial from the incomming data block. If check sum fails to compare the GETIT program will cause the data block to be retransmitted one time. If the second transmission of the data block also produces an error the GETIT program will output the error flag to the DAS data display. In all cases the MCS display refresh will be inhibited until the new data block, needed for refresh, passes the error check routine.

7.3.4.5 ERRIT, Figure 7-13 - This subroutine processes the errors and malfunctions in the system for display. The ERRIT routine maintains the pushbutton and DAS conflict tables and tests input commands, where possible, for conflict error that could cause system malfunctions.

7.3.4.6 SENIT, Figure 7-14 - The SENIT program formats and passes data to the communications link for transmission to the shear or to the roof supports. In the event a mode change is found in the data

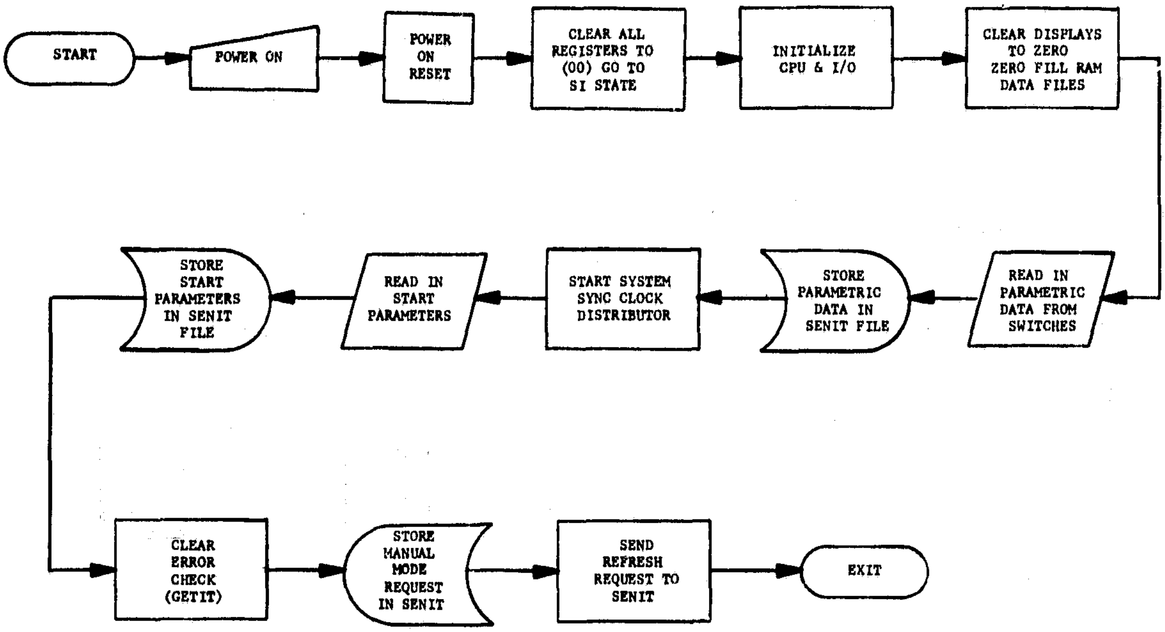


Figure 7-11. Power On Initialization Routine (START)

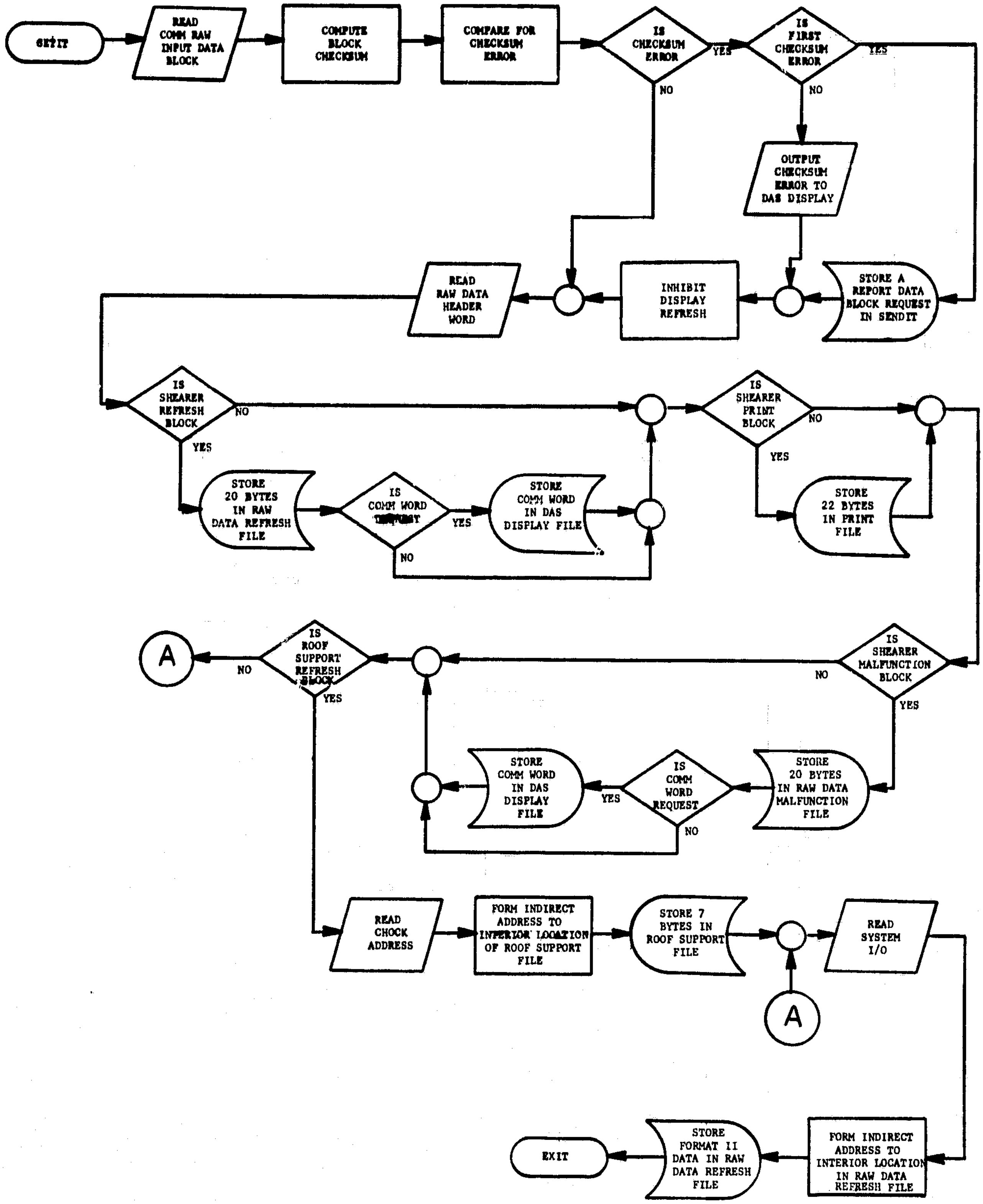


Figure 7-12. Data Format Routine (GETIT)

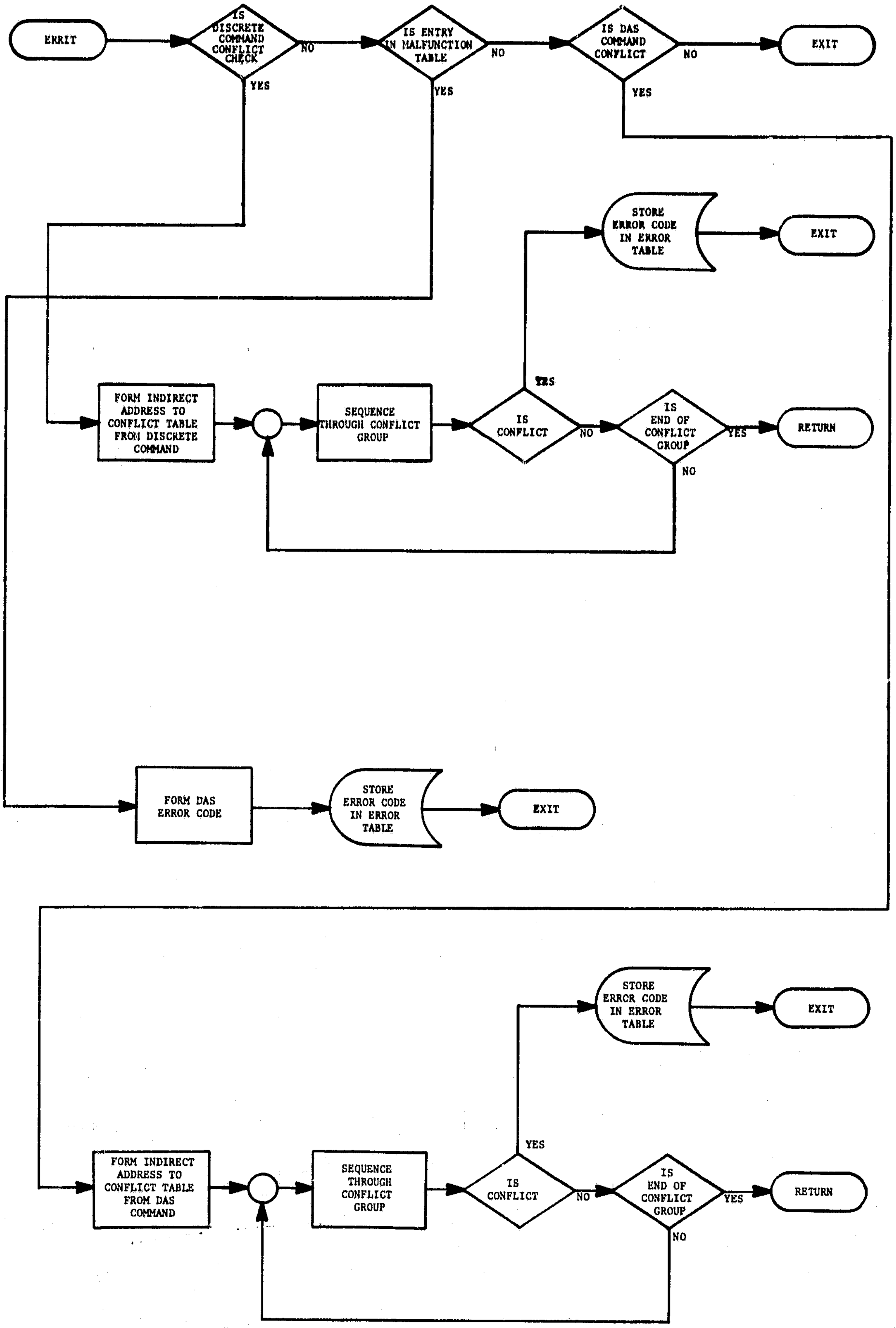


Figure 7-13. Error Check Routine (ERRIT)

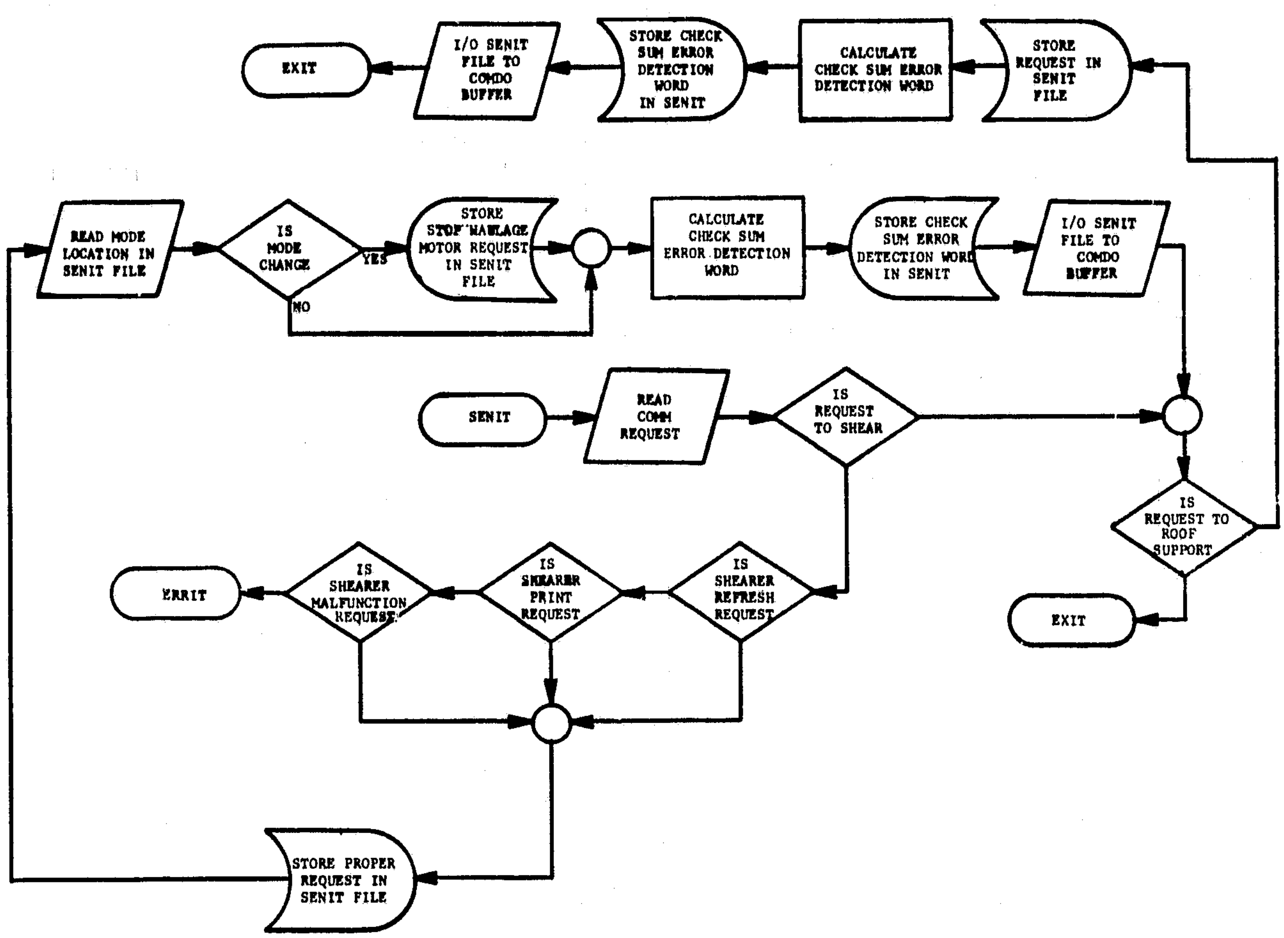


Figure 7-14. Communications Management Routine (SENIT)

block the SENIT routine will stop the haulage motor. At the end of all transmissions it passes control to BOSS so as to be able to process receive data on the next cycle.

7.3.4.7 REMOT, Figure 7-15 - The REMOT subroutine monitors all discrete buttons, when activated by the keyswitch, and presents status to the SENIT program for formatting and transmission to the shearer. This subroutine also updates the FRSUP file for display of pushbutton status. This program also verifies conflicts in pushbutton operation and inhibits control when such conflicts exist.

7.3.4.8 DASGO, Figure 7-16 - The DASGO program is the routine that operates the DAS keyboard and display. This program does all of the housekeeping for display and control such as, code conversion, operation of button algorithms, display of error codes, maintenance of write lock and preformatting of data for transmission to the SENIT file.

The DASGO program also contains a utility routine that is not normally accessed by the BOSS monitor. In the event that recalibration is required for the coal interface detector (CID) a routine may be called up through the DAS keyboard to calculate the polynomial coefficients for introduction into the digit switches on the MCS. This routine operates to provide a calculator like capability to the operator for the purpose of calculating and storing the results of the calculation in local memory. When the routine is called up it will request the operator to write into memory in signed exponential and signed mantissa form a number of measured coal thickness values in inches and the corresponding number of normalized CID counts associated with those measurements. The calculation then proceeds in the following way.

X_i = The CID count associated with the i^{th} measurement

D_i = The value of the i^{th} measurement in inches

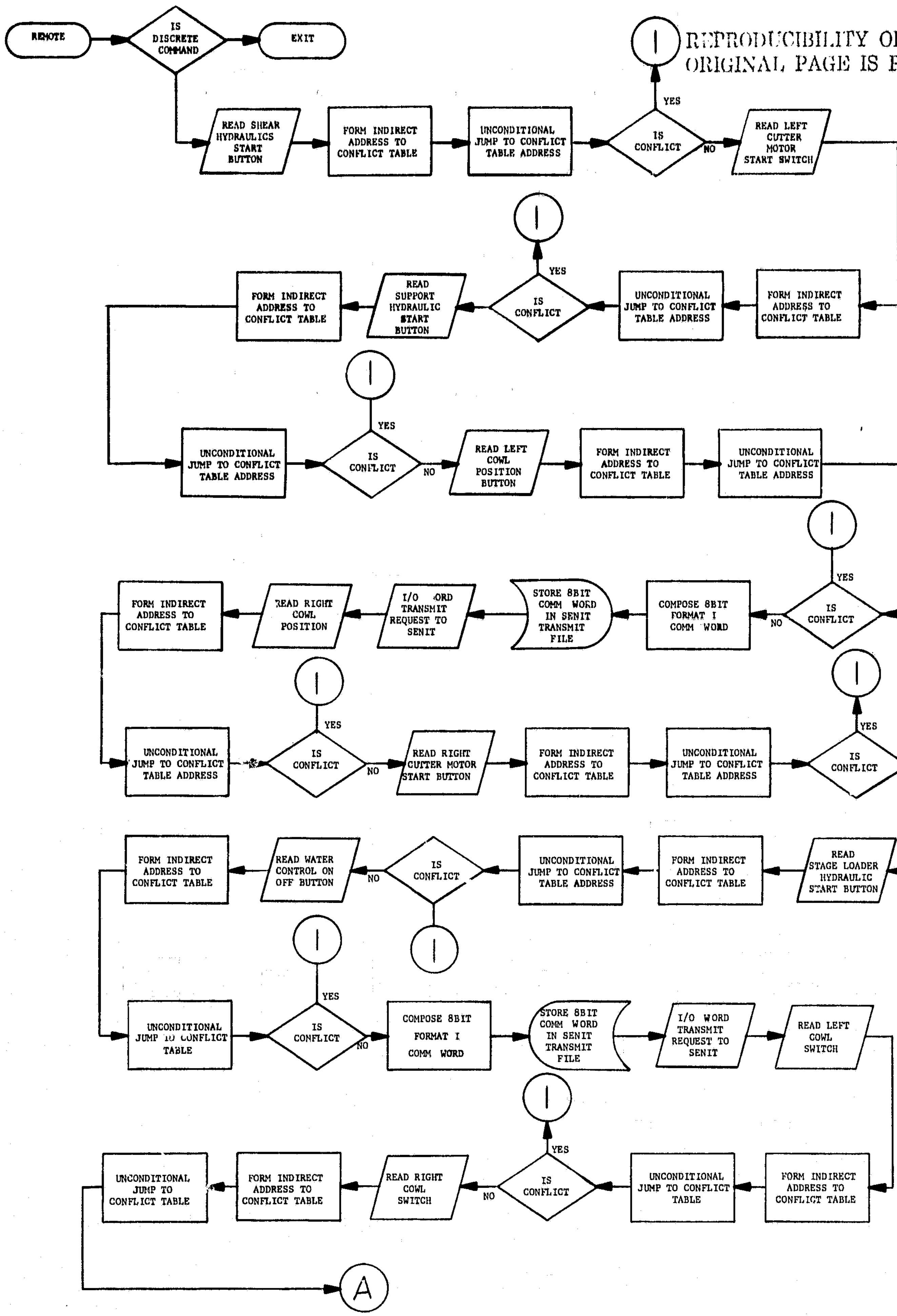


Figure 7-15. Remote Operation Routine (REMOT) (Page 1 of 2)

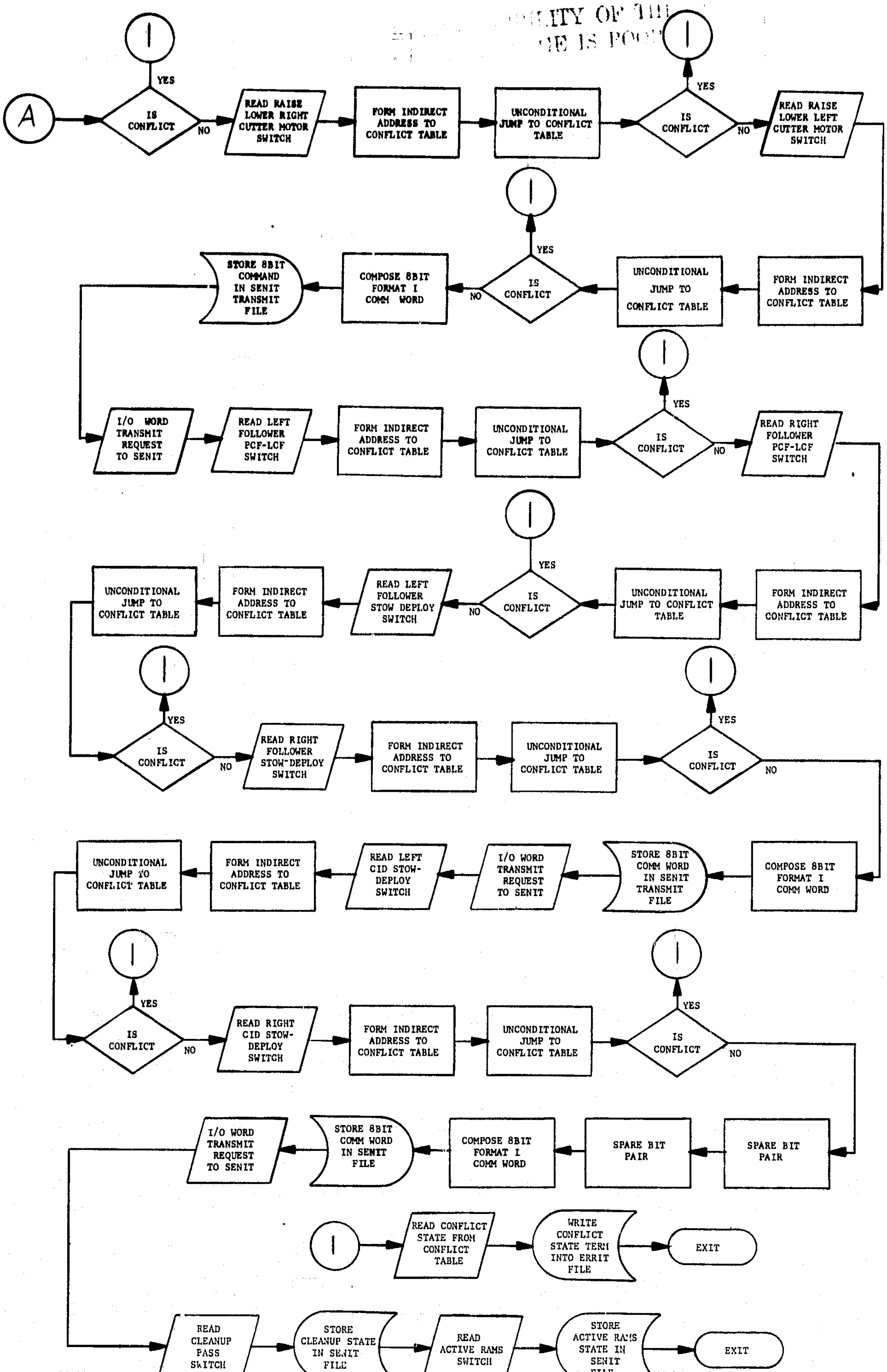


Figure 7-15. Remote Operation Routine (REMOT) (Page 2 of 2)

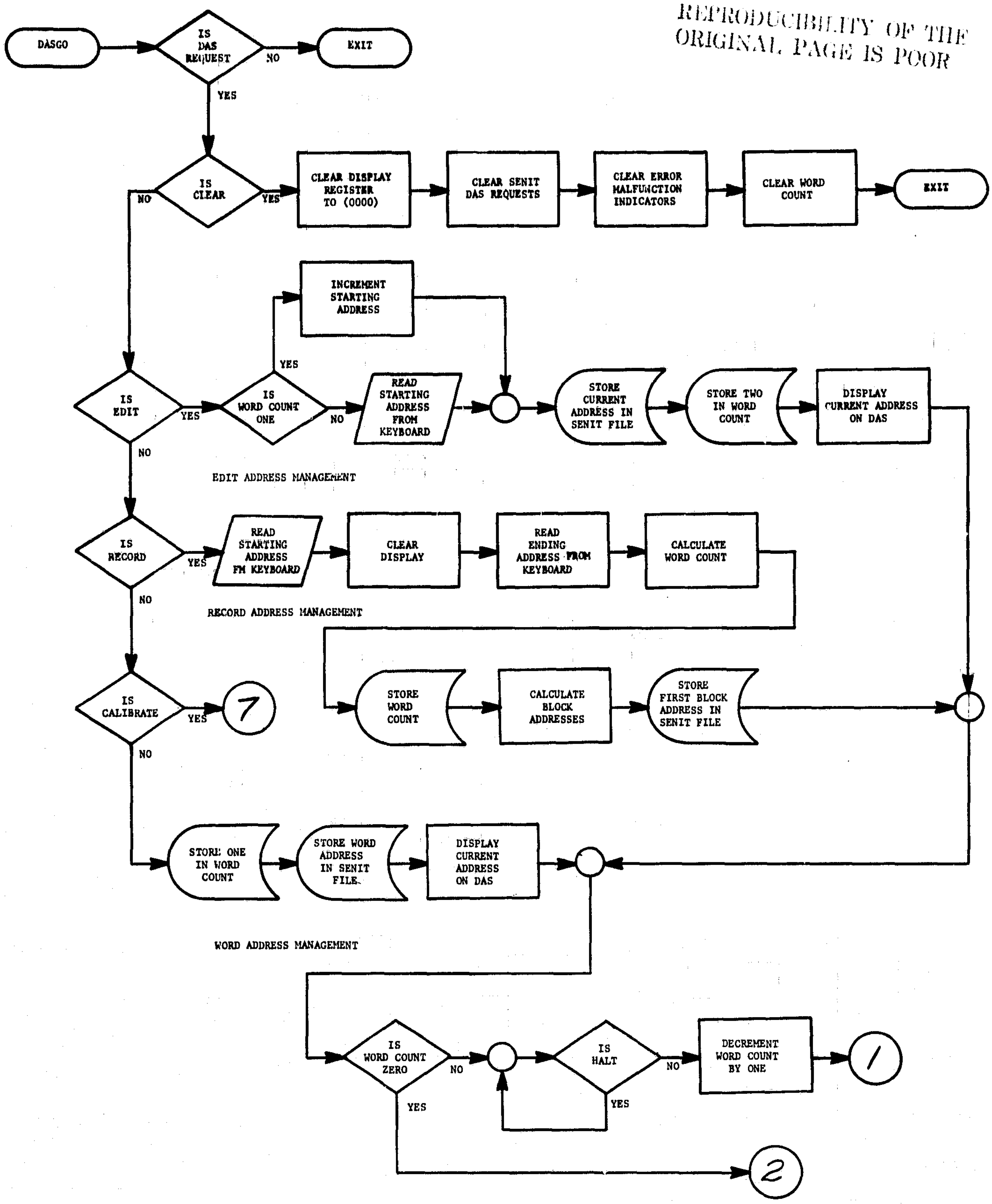


Figure 7-16. Digital Address Display Management (DASGO) (Page 1 of 3)

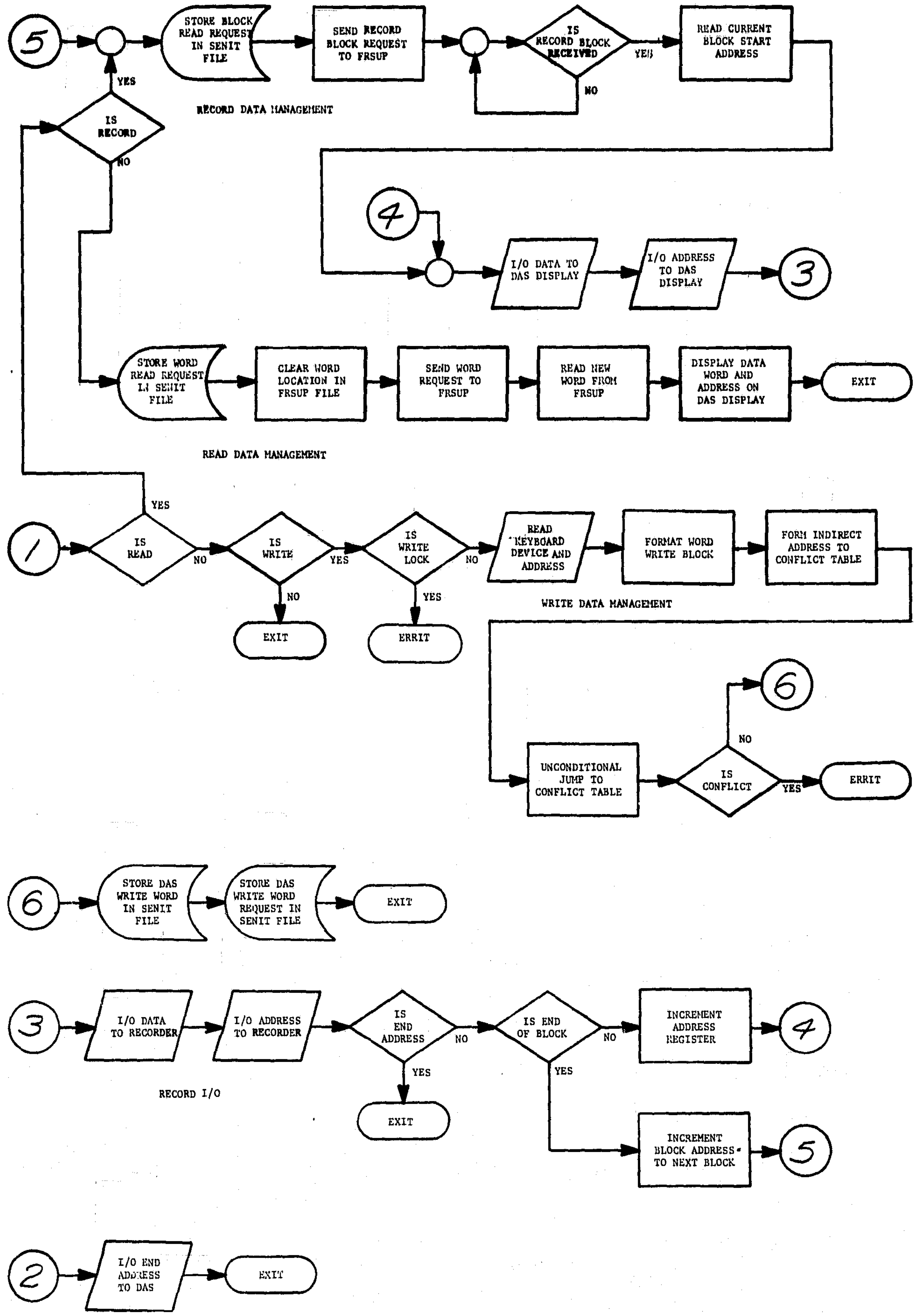
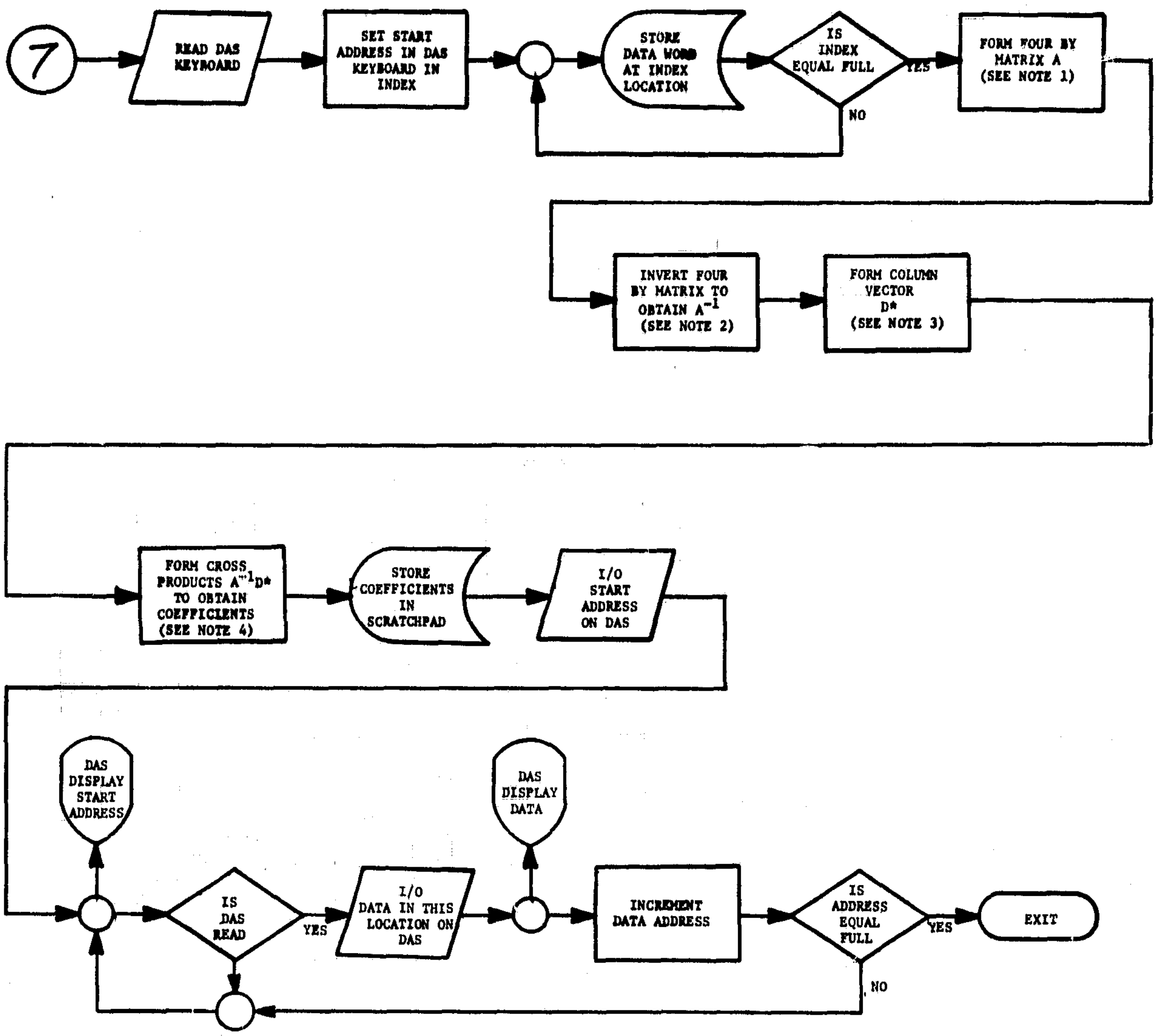


Figure 7-16. Digital Address Display Management (DASGO) (Page 2 of 3)



NOTE 1 MATRIX 1

$$\begin{bmatrix} \sum x_i^4 & \sum x_i^3 & \sum x_i^2 & \sum x_i & 4 \\ \sum x_i^5 & \sum x_i^4 & \sum x_i^3 & \sum x_i^2 & \sum x_i \\ \sum x_i^6 & \sum x_i^5 & \sum x_i^4 & \sum x_i^3 & \sum x_i^2 \\ \sum x_i^7 & \sum x_i^6 & \sum x_i^5 & \sum x_i^4 & \sum x_i^3 \\ \sum x_i^8 & \sum x_i^7 & \sum x_i^6 & \sum x_i^5 & \sum x_i^4 \end{bmatrix} = A$$

NOTE 2 MATRIX INVERSE

$$\begin{bmatrix} \alpha_1 & \beta_1 & \gamma_1 & \delta_1 & \epsilon_1 \\ \alpha_2 & \beta_2 & \gamma_2 & \delta_2 & \epsilon_2 \\ \alpha_3 & \beta_3 & \gamma_3 & \delta_3 & \epsilon_3 \\ \alpha_4 & \beta_4 & \gamma_4 & \delta_4 & \epsilon_4 \\ \alpha_5 & \beta_5 & \gamma_5 & \delta_5 & \epsilon_5 \end{bmatrix} = A^{-1}$$

NOTE 3 COLUMN VECTOR

$$\begin{bmatrix} \sum D_i \\ \sum D_i x_i \\ \sum D_i x_i^2 \\ \sum D_i x_i^3 \\ \sum D_i x_i^4 \end{bmatrix} = D^*$$

NOTE 4 SOLUTION FOR CONSTRAINTS $(A^{-1})(D^*)$

$$a = \alpha_1 \sum D_i + \beta_1 \sum D_i x_i + \gamma_1 \sum D_i x_i^2 + \delta_1 \sum D_i x_i^3 + \epsilon_1 \sum D_i x_i^4$$

$$b = \alpha_2 \sum D_i + \beta_2 \sum D_i x_i + \gamma_2 \sum D_i x_i^2 + \delta_2 \sum D_i x_i^3 + \epsilon_2 \sum D_i x_i^4$$

$$c = \alpha_3 \sum D_i + \beta_3 \sum D_i x_i + \gamma_3 \sum D_i x_i^2 + \delta_3 \sum D_i x_i^3 + \epsilon_3 \sum D_i x_i^4$$

$$d = \alpha_4 \sum D_i + \beta_4 \sum D_i x_i + \gamma_4 \sum D_i x_i^2 + \delta_4 \sum D_i x_i^3 + \epsilon_4 \sum D_i x_i^4$$

$$e = \alpha_5 \sum D_i + \beta_5 \sum D_i x_i + \gamma_5 \sum D_i x_i^2 + \delta_5 \sum D_i x_i^3 + \epsilon_5 \sum D_i x_i^4$$

$x_1, x_2, \ldots\ldots x_i$ = NORMALIZED CID COUNT OF i^{th} MEASUREMENT

$D_1, D_2, \ldots\ldots D_i$ = ACTUAL COAL DEPTH OF i^{th} MEASUREMENT

Figure 7-16. Digital Address Display Management (DASGO) (Page 3 of 3)

The routine will form a fourth order matrix in memory so:

$$A = \begin{bmatrix} \sum x_i^4 & \sum x_i^3 & \sum x_i^2 & \sum x_i & \sum 4 \\ \sum x_i^5 & \sum x_i^4 & \sum x_i^3 & \sum x_i^2 & \sum x_i \\ \sum x_i^6 & \sum x_i^5 & \sum x_i^4 & \sum x_i^3 & \sum x_i^2 \\ \sum x_i^7 & \sum x_i^6 & \sum x_i^5 & \sum x_i^4 & \sum x_i^3 \\ \sum x_i^8 & \sum x_i^7 & \sum x_i^6 & \sum x_i^5 & \sum x_i^4 \end{bmatrix}$$

then it will invert this matrix so:

$$A^{-1} = \begin{bmatrix} \alpha_1 & \beta_1 & \gamma_1 & \delta_1 & \varepsilon_1 \\ \alpha_2 & \beta_2 & \gamma_2 & \delta_2 & \varepsilon_2 \\ \alpha_3 & \beta_3 & \gamma_3 & \delta_3 & \varepsilon_3 \\ \alpha_4 & \beta_4 & \gamma_4 & \delta_4 & \varepsilon_4 \\ \alpha_5 & \beta_5 & \gamma_5 & \delta_5 & \varepsilon_5 \end{bmatrix}$$

then it will form a column vector so:

$$D^* = \begin{bmatrix} \sum D_i \\ \sum D_i X_i \\ \sum D_i X_i^2 \\ \sum D_i X_i^3 \\ \sum D_i X_i^4 \end{bmatrix}$$

then it will form the vector cross products so:

$$K_3 = (A^{-1})D^*$$

Expanded: $a = \alpha_1 D_i + \beta_1 \sum D_i X_i + \gamma_1 \sum D_i X_i^2 + \delta_1 \sum D_i X_i^3 + \epsilon_1 \sum D_i X_i^4$

$$b = \alpha_2 D_i + \beta_2 \sum D_i X_i + \gamma_2 \sum D_i X_i^2 + \delta_2 \sum D_i X_i^3 + \epsilon_2 \sum D_i X_i^4$$

$$c = \alpha_3 D_i + \beta_3 \sum D_i X_i + \gamma_3 \sum D_i X_i^2 + \delta_3 \sum D_i X_i^3 + \epsilon_3 \sum D_i X_i^4$$

$$d = \alpha_4 D_i + \beta_4 \sum D_i X_i + \gamma_4 \sum D_i X_i^2 + \delta_4 \sum D_i X_i^3 + \epsilon_4 \sum D_i X_i^4$$

$$e = \alpha_5 D_i + \beta_5 \sum D_i X_i + \gamma_5 \sum D_i X_i^2 + \delta_5 \sum D_i X_i^3 + \epsilon_5 \sum D_i X_i^4$$

After the conclusion of the calculation the end code is presented to the operator on the DAS display. He may then read the data from local memory and enter it into the parametric digit switches. In the event of power loss the data in local memory will be lost; the data on the digit switches, of course, will not be lost.

These parametric inputs to the system will be used in the polynomial calculation at the shearer to transform the normalized CID count into the scaled coal depth in inches. The process, performed in the shearer, periodically, iterates solutions to the following polynomial:

$$T = aX^4+bX^3+cX^2+dX+e$$

Where:

T = Coal thickness in inches

X = CID Count

a,b,c,d,e, = Polynomial Constants

7.4 Master Control Station Component Selection - The baseline component selection was made on the basis of meeting functional requirements with equipment components that are typical of a final selection. Cost and availability were considered as well as power and operability. In most cased, there was no conflict between engineering considerations and user requirements. The power requirement for the LCD and the LED differ greatly with the LCD being much more power efficient. Unless there were significant user advantages in the use of LED displays for numeric readouts, the electrical engineering preferences would be for LCD. To resolve that question, representative displays of each type were selected for comparison. Both numeric displays had 0.30" character height which is readable for all anticipated viewing distances. The LCD were standard Hamlins and the LED displays were distributed by Radio Shacks, both of the displays contained four numerals and the decimal (Hamlin 3918-312, Archer RS276-053). Based on manufacturer data, it was anticipated that the LED

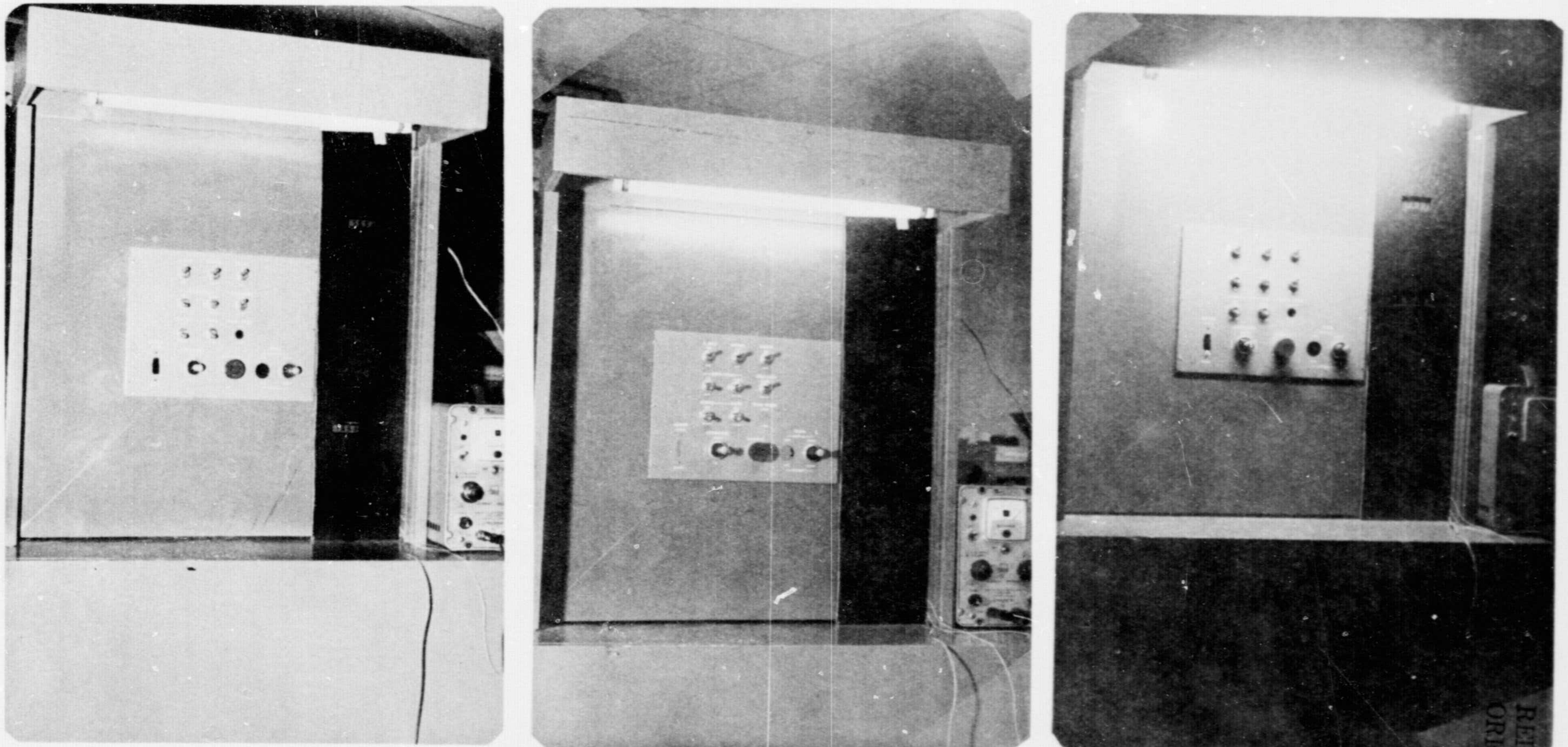
displays would be more readable over a wider viewing range and variation of light intensity.

A test apparatus was set up to represent the lighting conditions and viewing requirements under anticipated conditions of use. Direct lighting was provided by a 15 watt GE F15T8-CW "cool white" lamp mounted in an adjustable pull out above a console such that the displays could be viewed without looking into the lamp. The test apparatus is shown in Figure 7-17. The LCD was positioned above and below the LED display and the same numbers activated. Six persons from the drafting and administration departments who were not familiar with the engineering considerations viewed the displays using only the test fixture lamp and under bright room illumination and the lamp conditions. The viewers looked at the display directly and at an offset position such that the LCD were least sharply presented. The viewers were asked to judge which type of display was easier to read and invited to comment on their preferences. The preference results are summarized below:

	DIRECT VIEW		OFFSET VIEW	
	LED	LCD	LED	LCD
BRIGHT	6	2	6	0
DIM	6	0	6	0

A Chi square statistical test of the difference between the expected and observed frequencies resulted in a value of 36.3 which is significant at greater than the .001 level (20.52 for df = 5) so there is a clear and reliable preference for the LED displays under these conditions.

The viewer comments emphasized this difference and confirmed the assumption that only under ideal viewing conditions would the LCD be as satisfactory as the LED displays. The LED displays were therefore selected as the baselined display method. The other com-



A B C

Photograph A was taken under flood lighted conditions, B under room lighting and C under console lighting only. While camera recordings cannot duplicate visual presentations, the increased superiority of the LED display under operational conditions is indicated by the photographs.

Figure 7-17. Visual Comparison of LED's and LCD's

ponents on the control and display array are

Toggles, MIL 3950 Series 8500 Cutler Hammer
Mechanical Setter, Cherry T-20 Series
Indicating Switches, Microswitch DS-J0010
Keyboard, Mohawk Deta Sciences 71642

which are representative of the readability and operability requirements. Electrical and mechanical requirements are also met by these or equivalent components. The interior components of the console and connectors were selected by the same criteria as the balance of the electrical system using identical components. The card system was selected for its ruggedness and ease of access through the console side panel and meets the same requirements imposed on the Electronic Control Module.

7.5 MCS Electronics - The MCS, located on the stage loader, in the headgate area, is the central control and monitoring station for the Automated Longwall Guidance and Control System. The (ECM) is the Electronics Control Module control for the longwall shearer automation. The MCS is the control for the human/machine interface.

7.5.1 MCS Electronic Design - The previous VCS (Vertical Control System) report made reference to the MCS, as did Section 4.3 of this report. Both the VCS and the YAS operations and status monitoring requirements have dictated the control switches and displays used. Additional considerations in the selection criteria were those of power consumption and interface characteristics with respect to the remaining electronics within the MCS.

7.5.2 Top Level Trade-Offs - Several trade studies were conducted relative to the implementation hardware and techniques employed for the Vertical Control System (VCS) described in the previous report and the YAW alignment description of Section 4.3 of this report. These studies will not be reproduced in this section, however some of the pertinent results will be presented where applicable.

7.5.2.1 Digital vs Analog Implementation - The digital vs analog trade study made for the vertical control of the shearer, and the subsequent optimization for the YAW alignment, remains applicable for the Master Control Station design problem. The communications interface established with shearer and roof supports as well as the digital characteristics of digital controls and displays virtually mandate the digital design approach to the MCS.

7.5.2.2 Software vs Hardware Trade Offs - A software dependent implementation philosophy was selected to minimize the hardware while maximizing the flexibility of this evaluation system.

7.5.2.3 Multiplexing vs Direct Wire Lines - The direct wire line philosophy for transferring the data from the shearer mounted sensors to the shearer mounted ECM electronics was chosen and the

justification presented within the VCS report previously published. This direct line technique was also selected for transferring data from the roof support sensors to the roof support electronics and will be employed as the method of transferring data from the motor current and hydraulic sensors which terminate in the MCS.

The multiplexing of data was chosen for the transfer of data between shearer, roof supports and MCS. The selected scheme of synchronous, time division multiplexing provides for an easily controllable technique that can be altered to accommodate design changes during evaluation of the longwall automated mining system.

7.5.2.4 Minicomputer vs Microprocessor The microprocessor design approach, supported by auxiliary arithmetic logic units (ALU) has been selected as the best of the available implementation techniques for this application.

7.5.3 System Electronics - The MCS electronics is employed by the console operator in his control and monitoring function as well as the Vertical Control System as a source for calibration and control data, the Roll Control System for control data, and the YAW alignment system as a source for parametric data. Figure 4-7 is a block diagram showing how the longwall automation assemblies interface as well as the block diagram of the MCS, the ECM, and the YAS.

Figure 7-1 indicates the location of the MCS and its power supply which supplies the MCS with power and supplies the YAS electronics on each of the roof supports. This drawing indicates where sensor inputs are supplied to the MCS. Cable routing is shown in the drawing where it is practical to do so.

The MCS is bolted to the shearer as shown. Shock absorbing feet are employed as required to dampen vibrations encountered during operation.

The Power Supply box, is an explosion proof box. It is attached to the stage loader. Both the power supply box and the MCS are water

and dust proof. All of the high energy control elements which cannot be made intrinsically safe are mounted in the explosion proof power supply box. The outputs of the power supply box are either redundantly current limited to intrinsically safe levels or employ mine permissible explosion proof cables operating through packed glands. The MCS box is configured to be intrinsically safe by maintaining power levels and energy storage devices (i.e., capacitors and inductors) within acceptable limits. This makes all of the MCS electronics permissible or intrinsically safe.

7.5.4 Safety - Certain unsafe environmental characteristics of Longwall mining deserve special comments.

7.5.4.1 Methane - The methane monitors currently employed on the shearer and support equipment as well as its present control and shutdown procedures are still used for methane protection. The ECM and MCS accepts signals from the methane detectors for display. In addition to the display and warning the ECM will perform a redundant shutdown based upon methane levels $\geq$ 2%; Ref: VCS Control System, Phase II Report.

7.5.4.2 Roof Support Precautions - In order to provide safe penetration of the longwall mining face and roof support area by mining personnel, provisions have been incorporated within the design for access keys to be located on roof supports on each end of the longwall face. When penetration is desired a key is removed from its roof support which will disallow power to the shearer and roof support systems. Power can only be activated after all keys are returned to the roof support access key positions. Personnel should not enter the face area without possession of a key. This is essentially a procedural safety requirement.

7.5.4.3 Mine Permissibility - In order to make the MCS permissible those circuits and signals which cannot be made intrinsically safe are housed in an explosion proof box. Power and signals entering

or exiting from the explosion proof box shall pass through explosion proof glands and MSHA approved cable.

Control power (110VAC at 60 Hz) enters the explosion proof box from explosion proof cable through explosion proof glands. Power is regulated within the power supply boxes and is reduntantly current limited to intrinsically safe levels prior to its routing to External loads. These intrinsically safe power levels are specified by a series of curves depending on resistance, inductance, and capacitance load values which are documented in the SMRE Research Report titled "Some Aspects of the Design of Intrinsically Safe Circuits" published by the Ministry of Power Safety in Mines Research Establishment", Red Hill, off BroadLane, Sheffield 3, England.

7.5.5 The Master Control System (MCS) Design - The MCS can be divided into five major subdivisions, i.e., signal conditioning, input/output, communication, central processing unit, and the control and display panel. The functions and operations of each of these parts are described briefly in the paragraphs which follow.

7.5.5.1 Signal Conditioning, Figure 7-18 The MCS signal conditioning has been configured to supply power to and receive signals from all the sensors located on the stage loader or in that proximity. The signals are the analog data from current transformers. The MCS signal conditioning also processes signals from all switches and controls on the control and display console. The MCS signal conditioning also provides the drive to all the indicators and displays on the control and display console.

7.5.5.2 Input/Output, Figure 7-19 - The input/output portion of the MCS is employed to store data until the processing and control computer has time to store and act upon that data. The input ports receive data from the signal conditioning and store it in 8 bit binary ports. At an appropriate time within the main processing and control computer algorithms, control signals are generated by the computer which place these 8 bit words on to the 8 bit data bus

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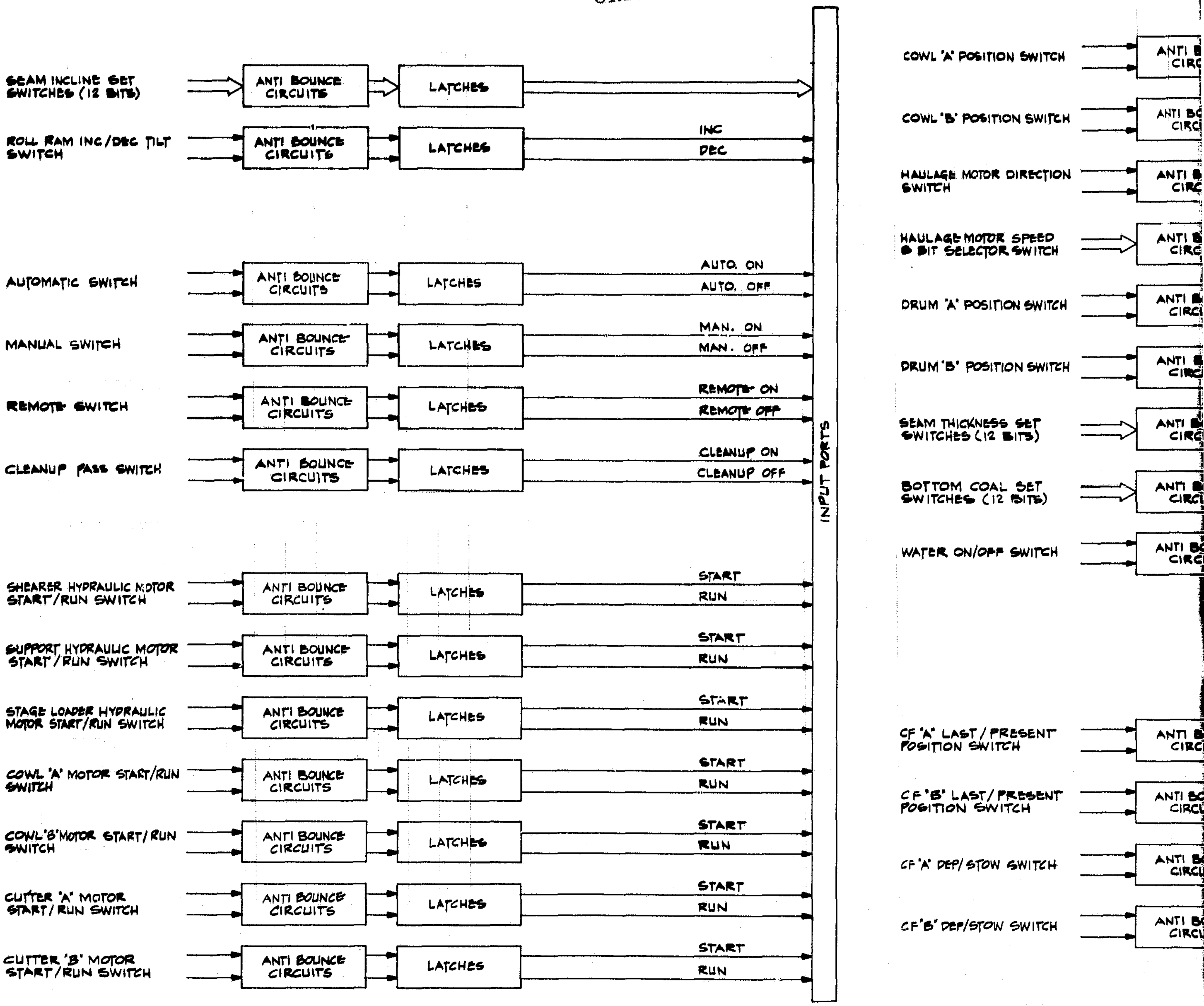

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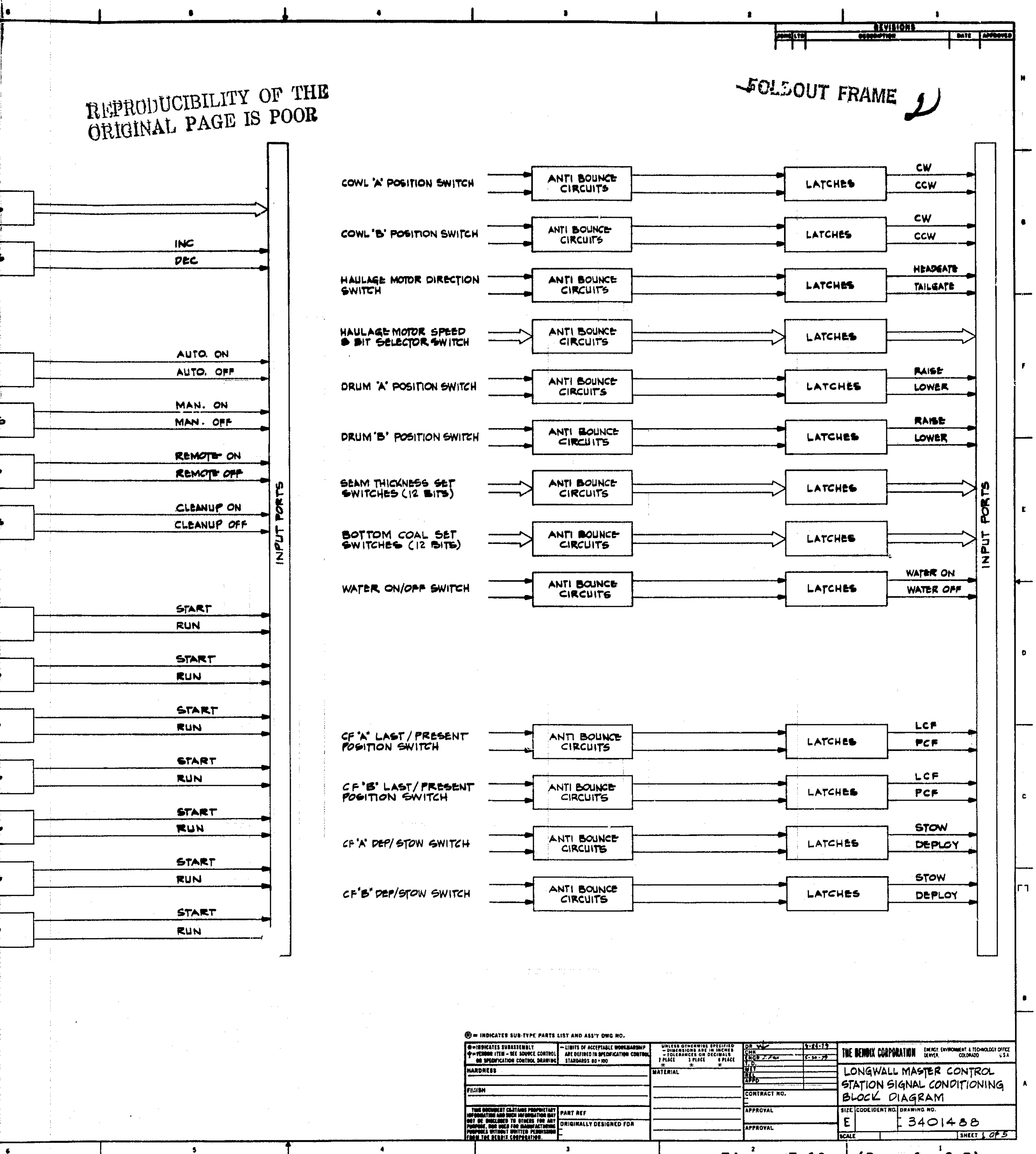

Figure 7-18. (Page 1 of 5)

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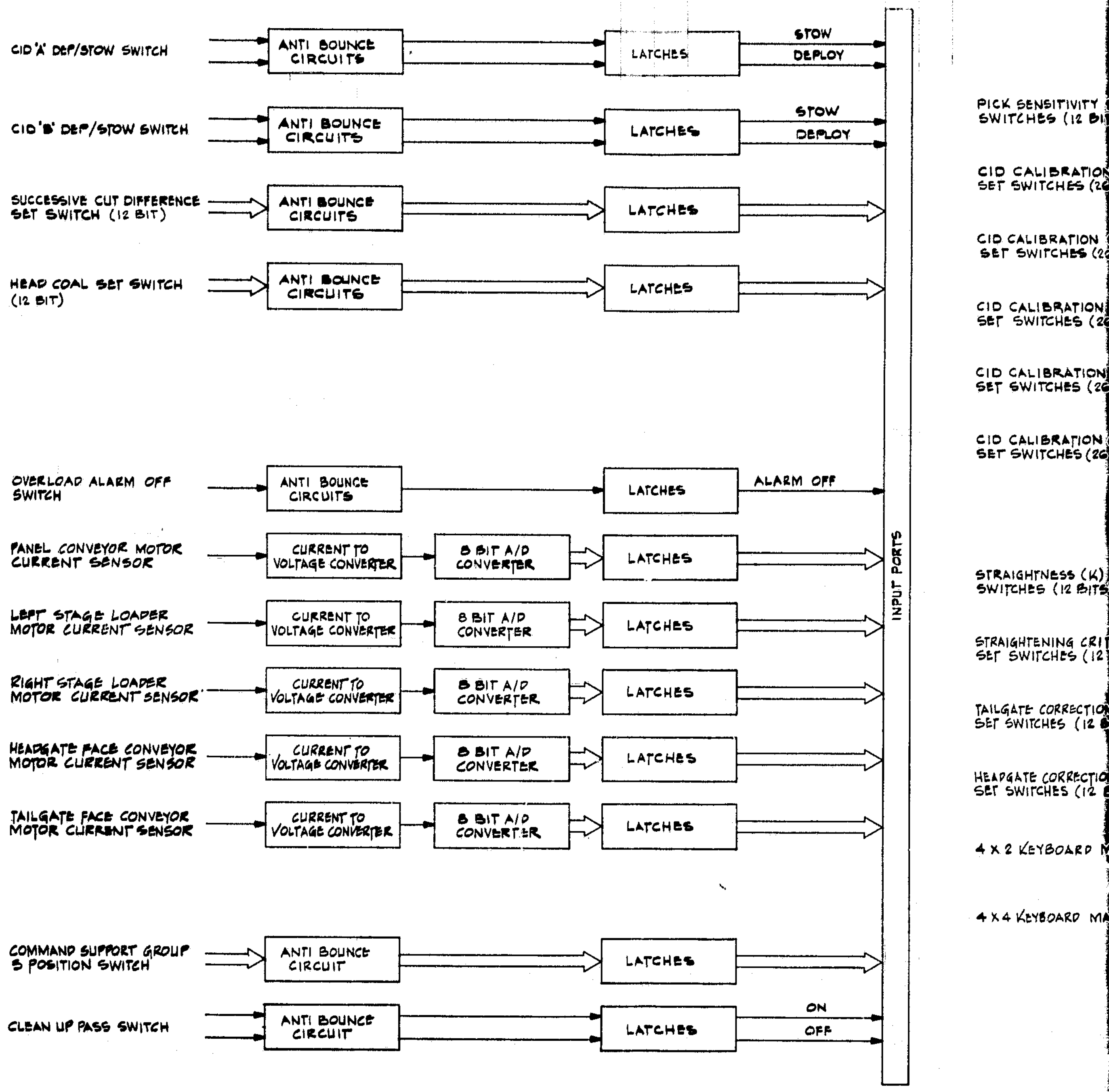

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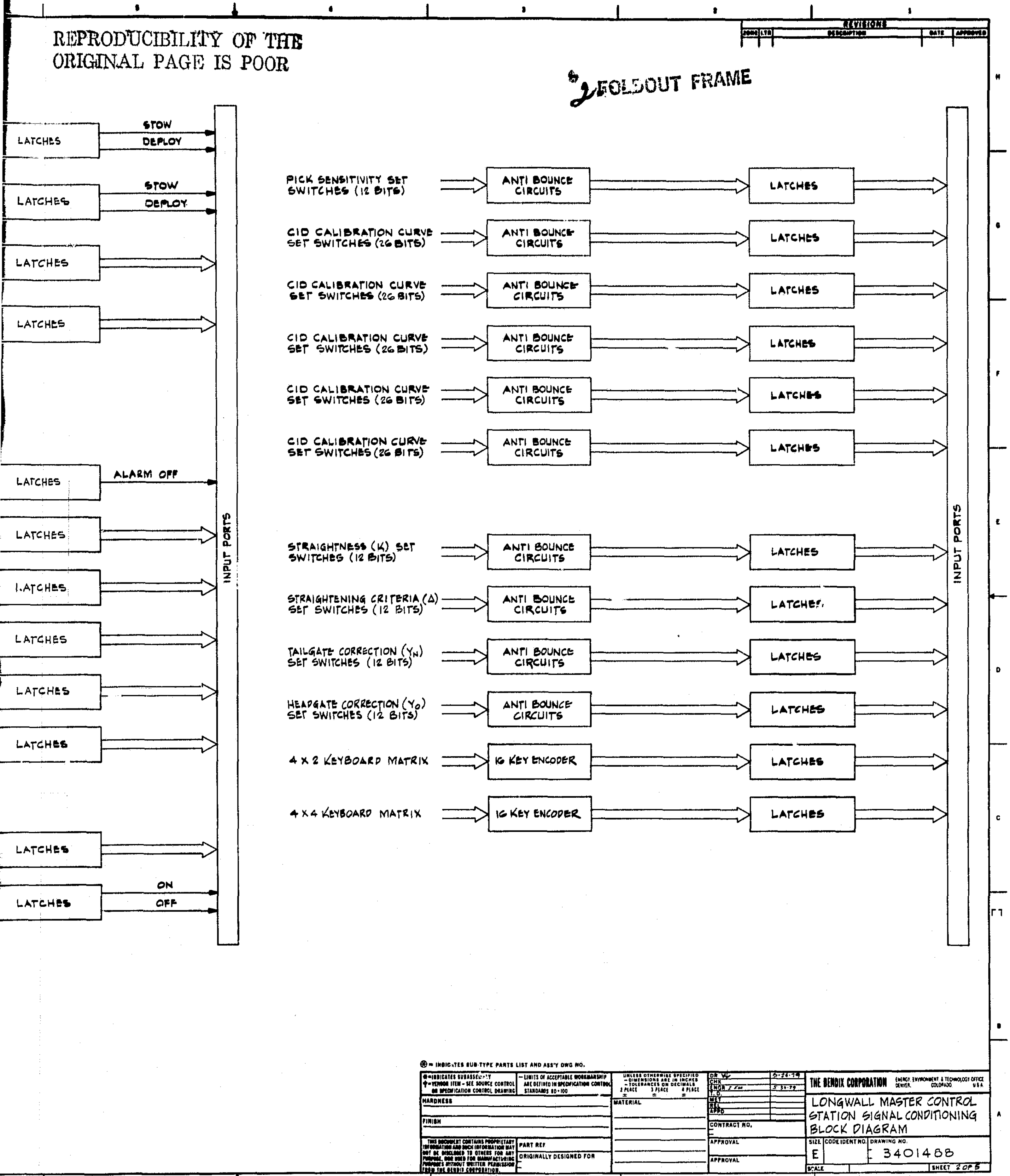

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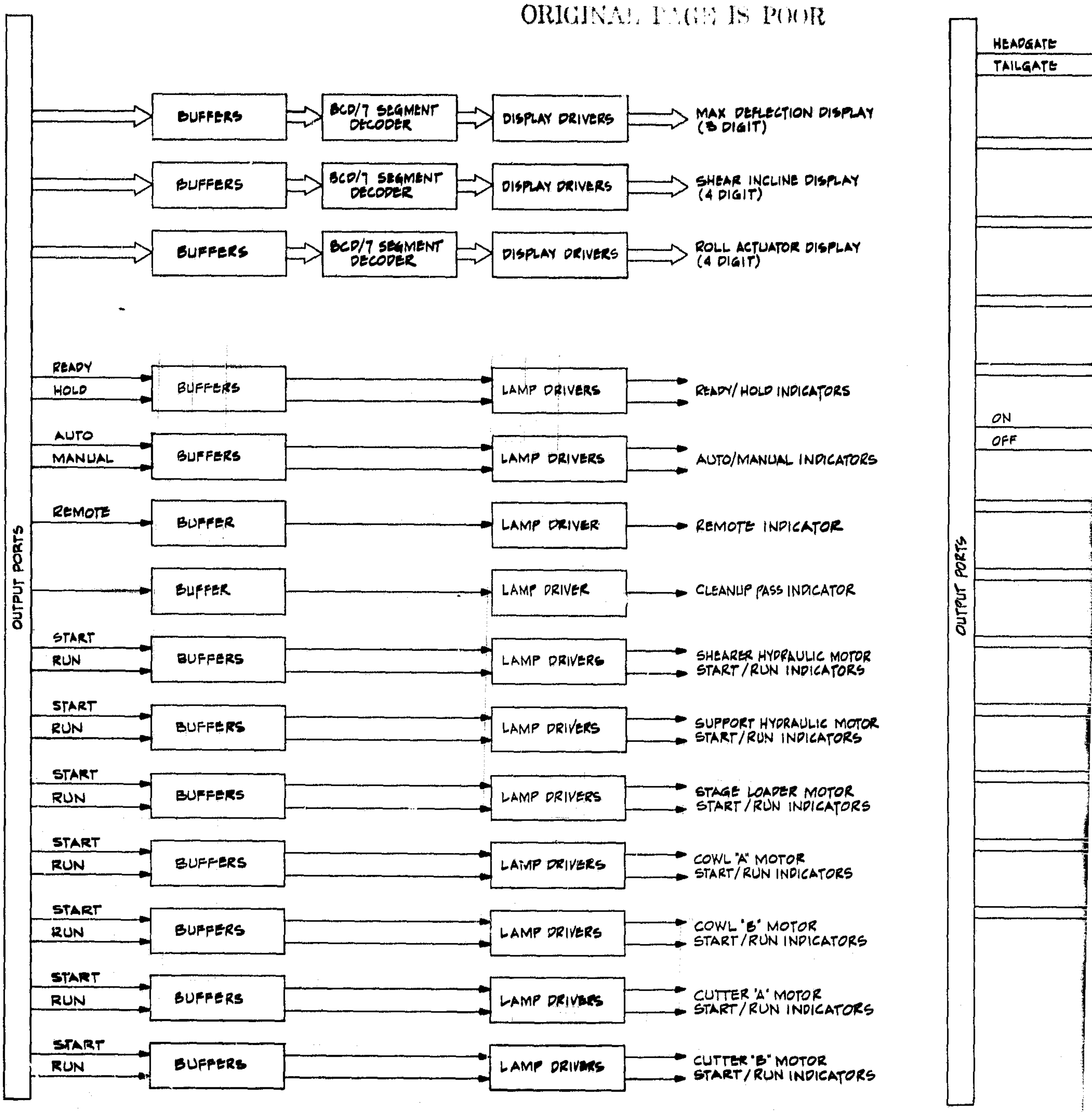

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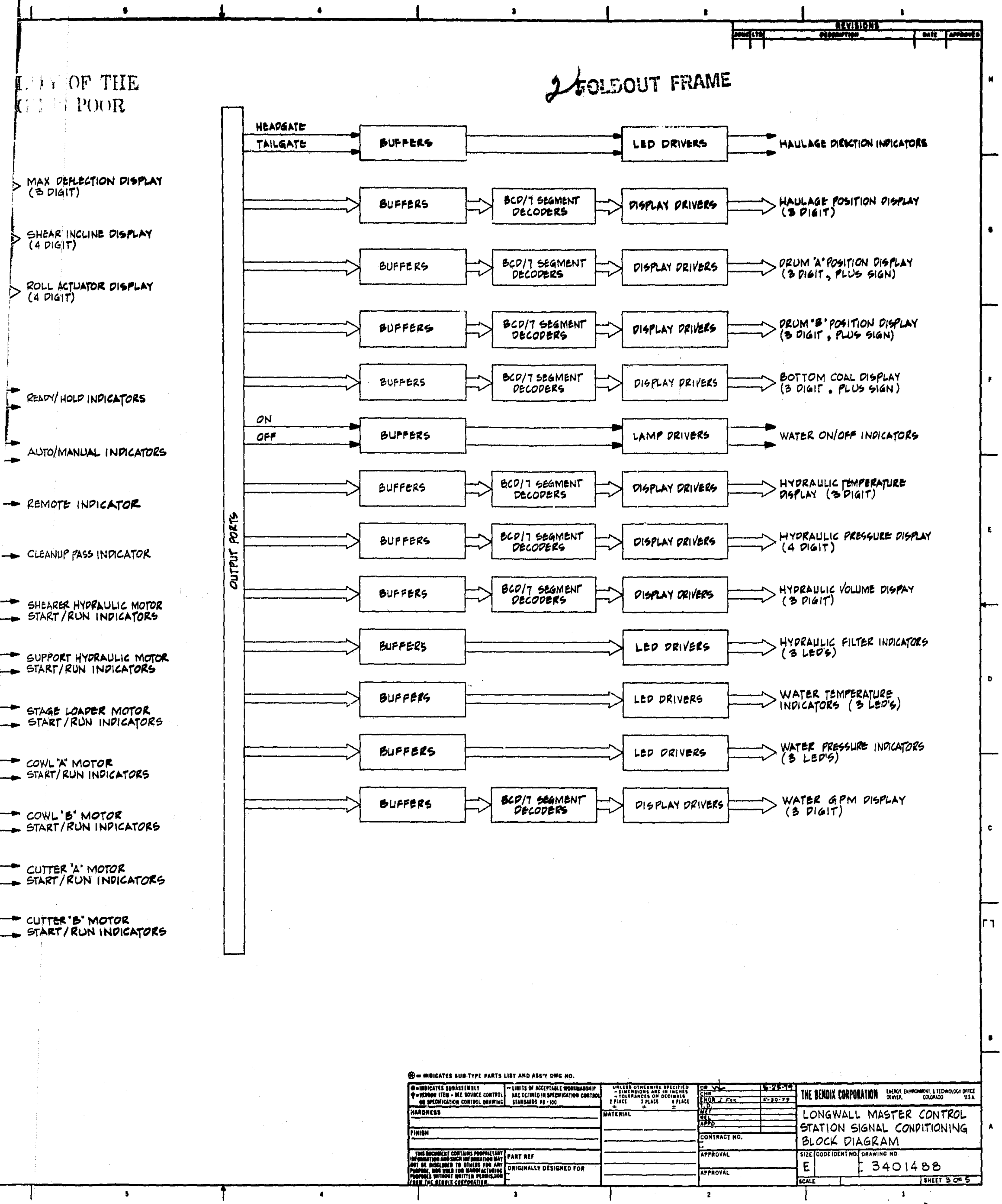

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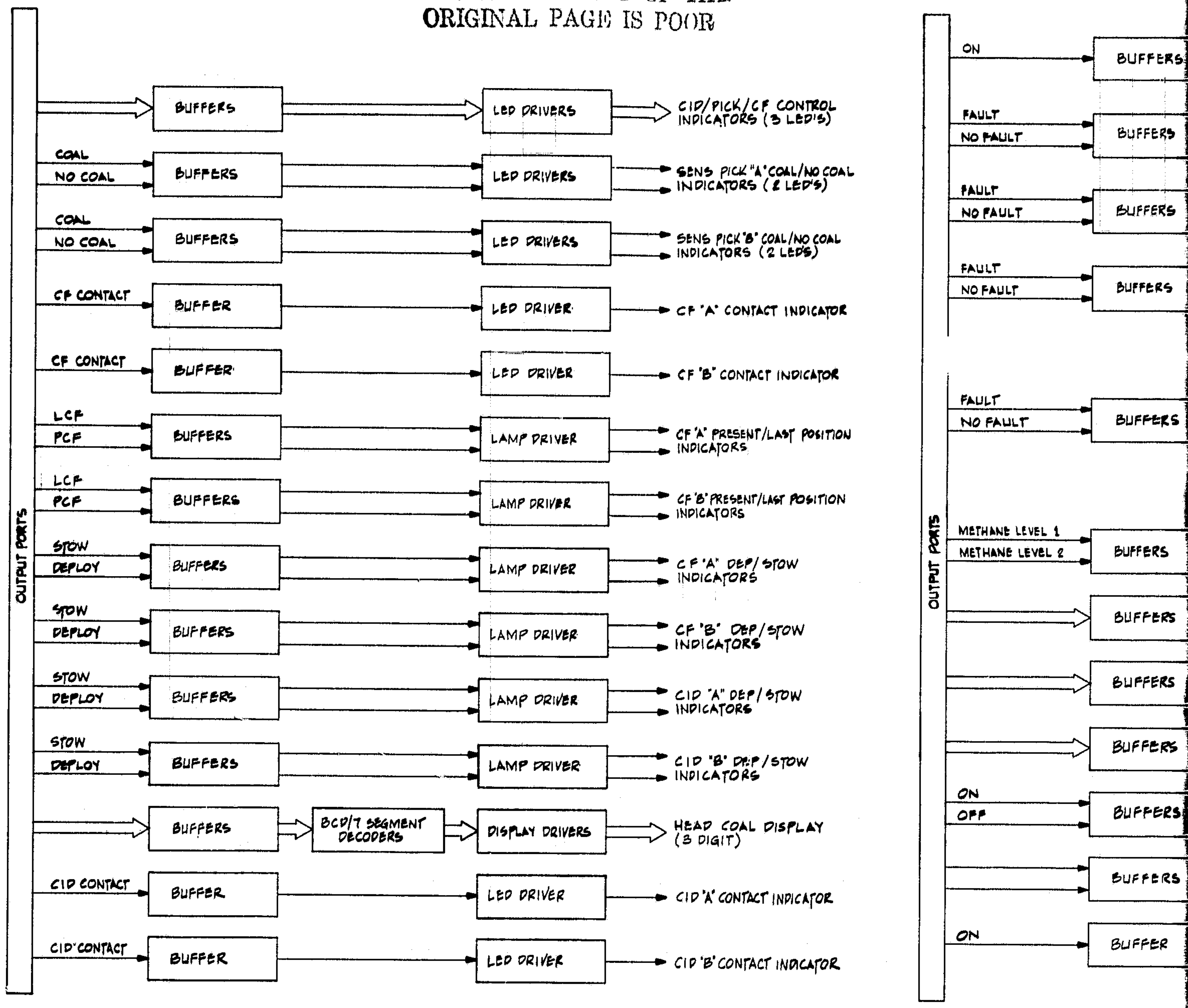

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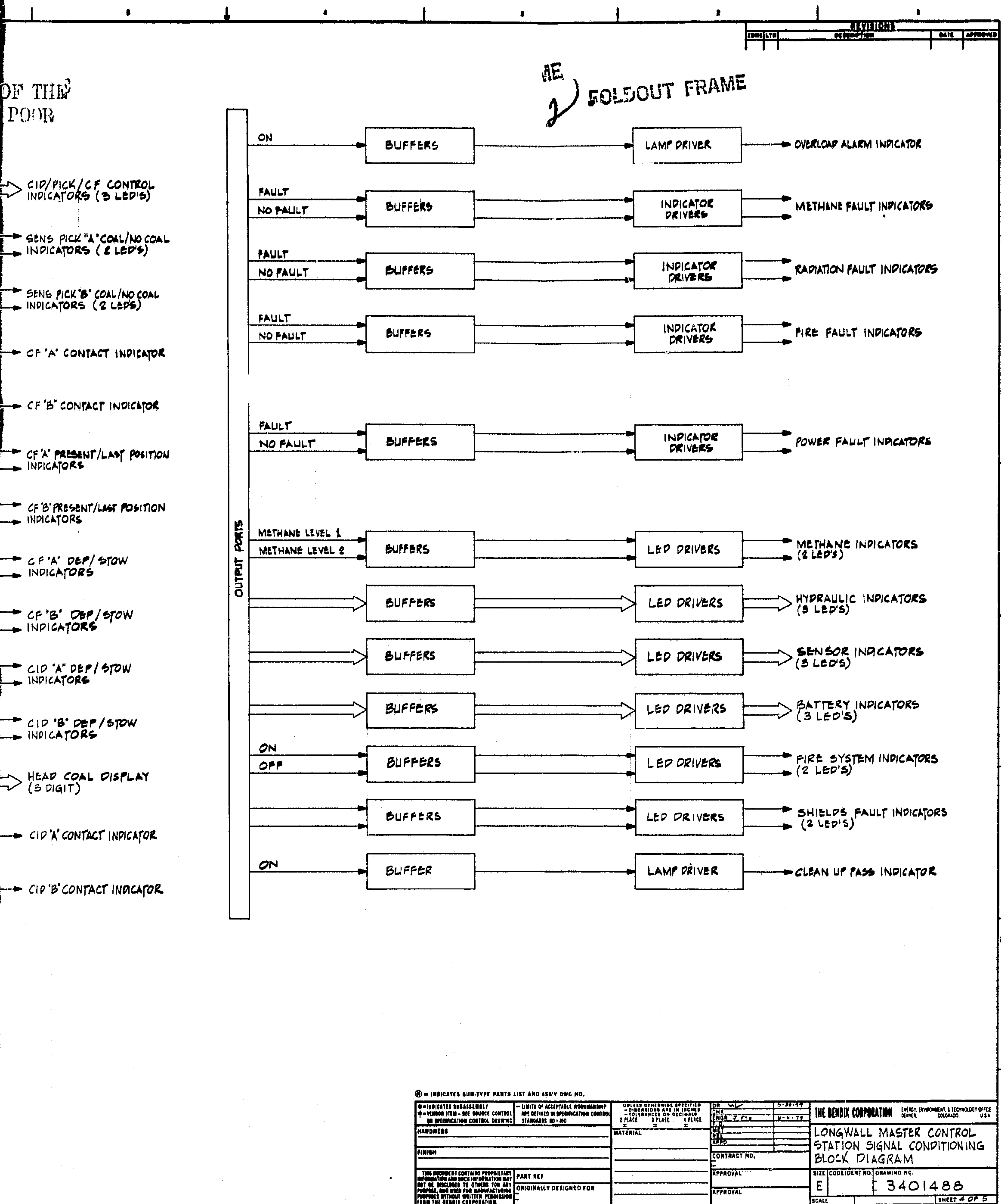
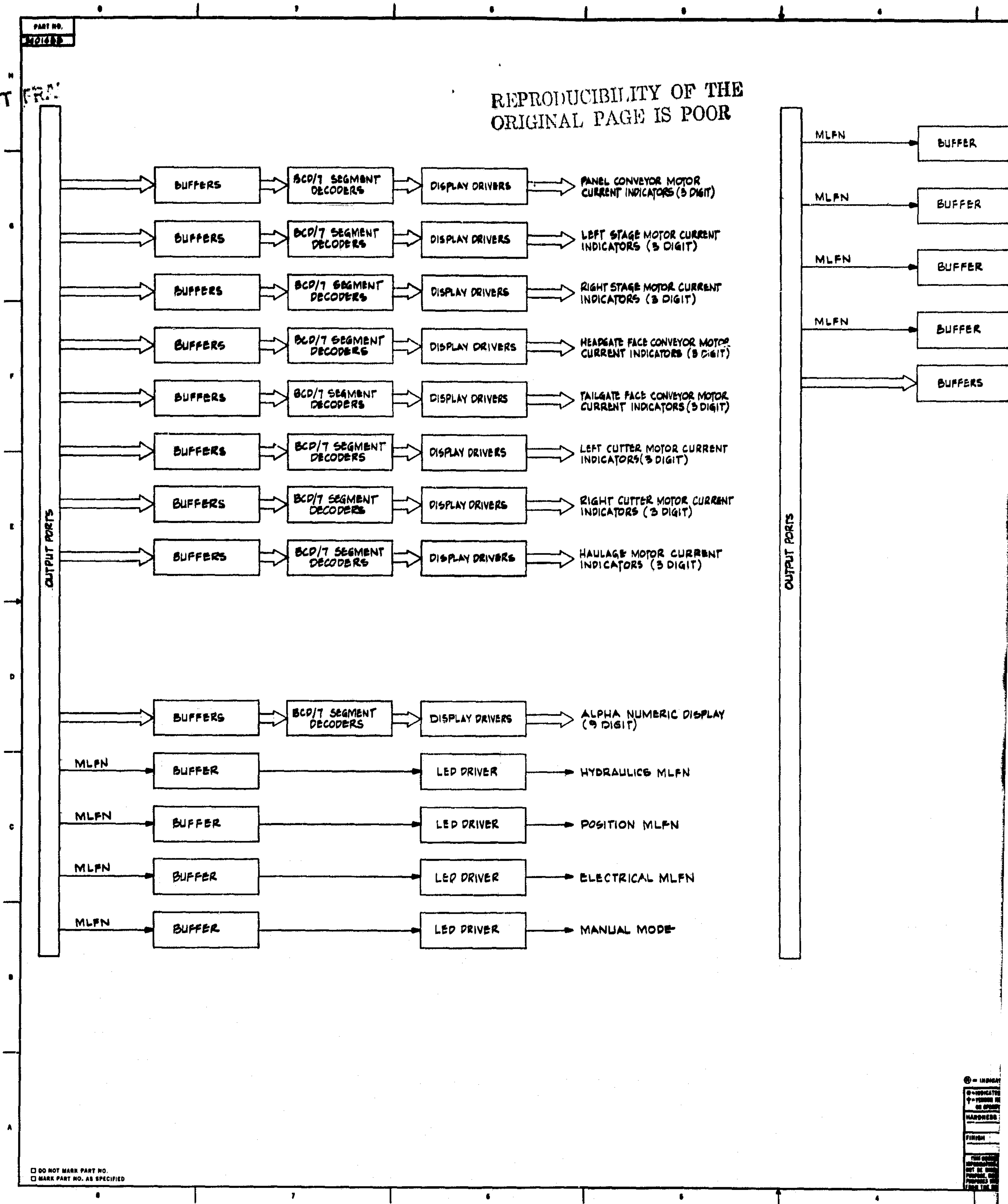


Figure 7-18. (Page 4 of 5)


OUTPUT PORTS
BUFFERS
BCD/7 SEGMENT DECODERS
DISPLAY DRIVERS
PANEL CONVEYOR MOTOR CURRENT INDICATORS (3 DIGIT)
LEFT STAGE MOTOR CURRENT INDICATORS (3 DIGIT)
RIGHT STAGE MOTOR CURRENT INDICATORS (3 DIGIT)
HEADGATE FACE CONVEYOR MOTOR CURRENT INDICATORS (3 DIGIT)
TAILGATE FACE CONVEYOR MOTOR CURRENT INDICATORS (3 DIGIT)
LEFT CUTTER MOTOR CURRENT INDICATORS (3 DIGIT)
RIGHT CUTTER MOTOR CURRENT INDICATORS (3 DIGIT)
HAULAGE MOTOR CURRENT INDICATORS (3 DIGIT)
ALPHA NUMERIC DISPLAY (9 DIGIT)
MLFN
BUFFER
LED DRIVER
HYDRAULICS MLFN
POSITION MLFN
ELECTRICAL MLFN
MANUAL MODE
OUTPUT PORTS
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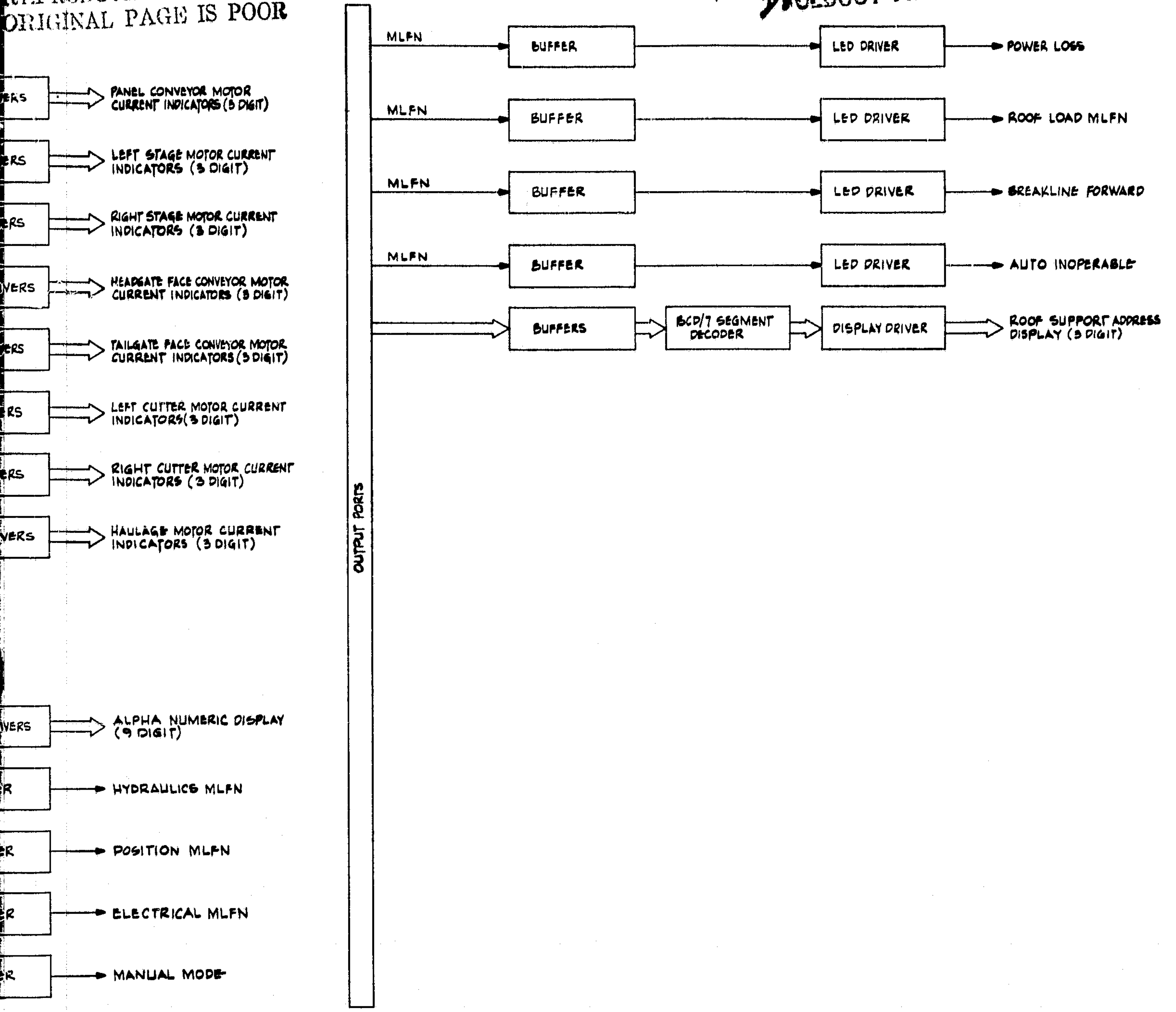

THE BENDIX CORPORATION ENERGY, ENVIRONMENT, & TECHNOLOGY OFFICE DENVER, COLORADO, U.S.A.

LONGWALL MASTER CONTROL STATION SIGNAL CONDITIONING BLOCK DIAGRAM

SIZE E DRAWING NO. 3401488 SHEET 5 OF 5

Figure 7-18. (Page 5 of 5)

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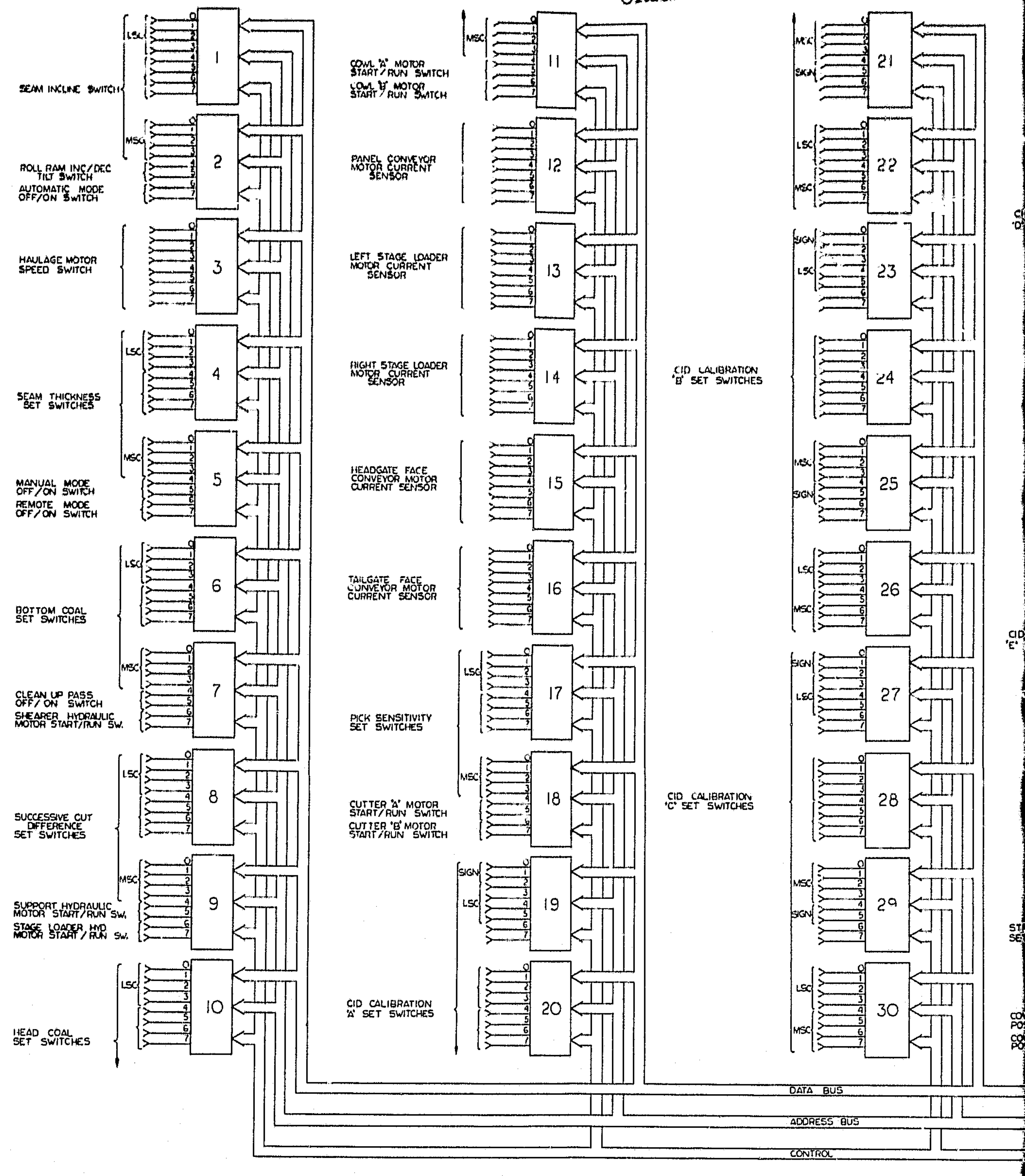

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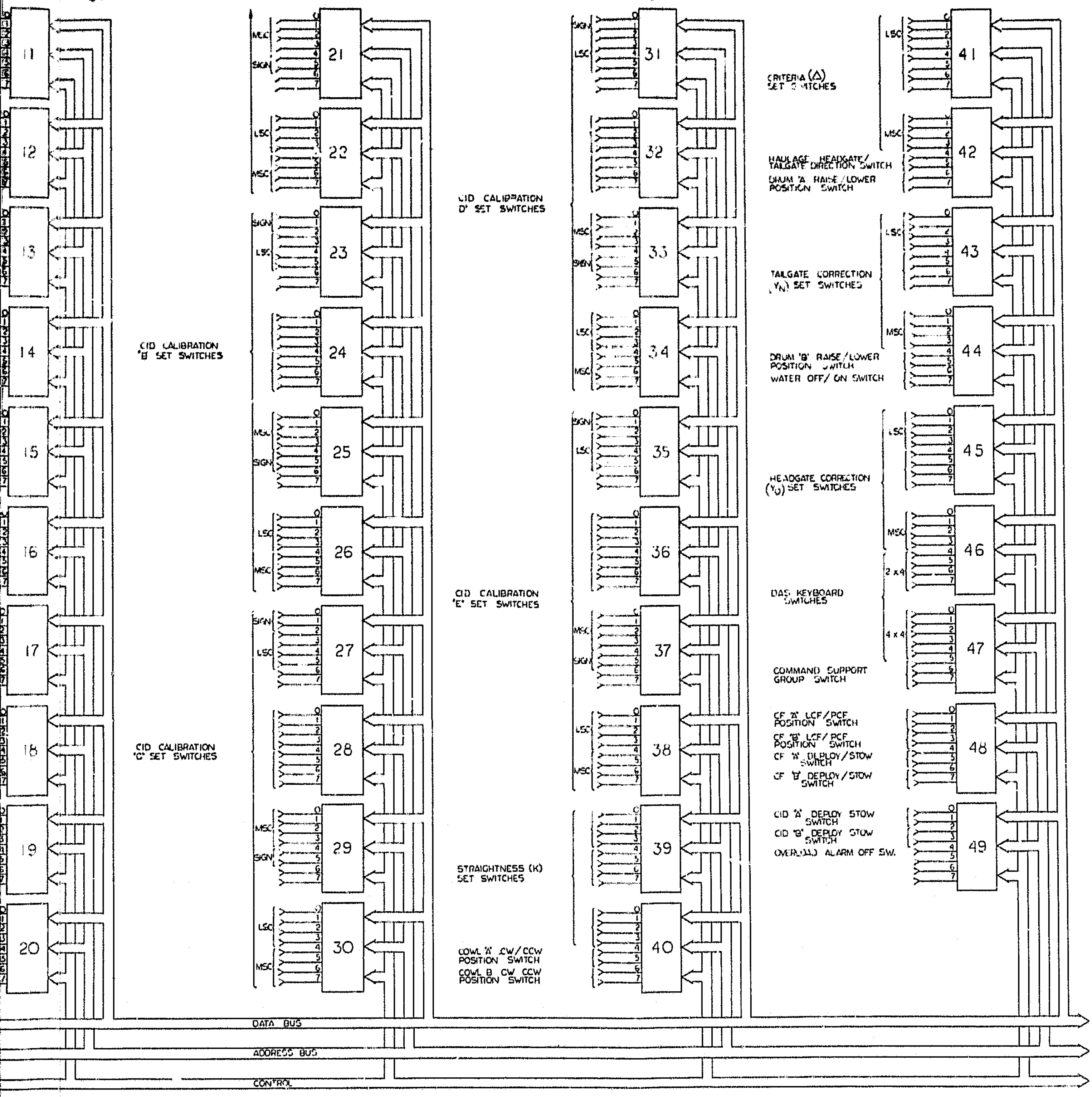

THE BENDIX CORPORATION	ENERGY, ENVIRONMENT & TECHNOLOGY OFFICE, DENVER, COLORADO, U.S.A.
Title	MCS INPUT/OUTPUT SYSTEM LONGWALL BLOCK DIAGRAM
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Figure 7-19. (Page 1 of 2)

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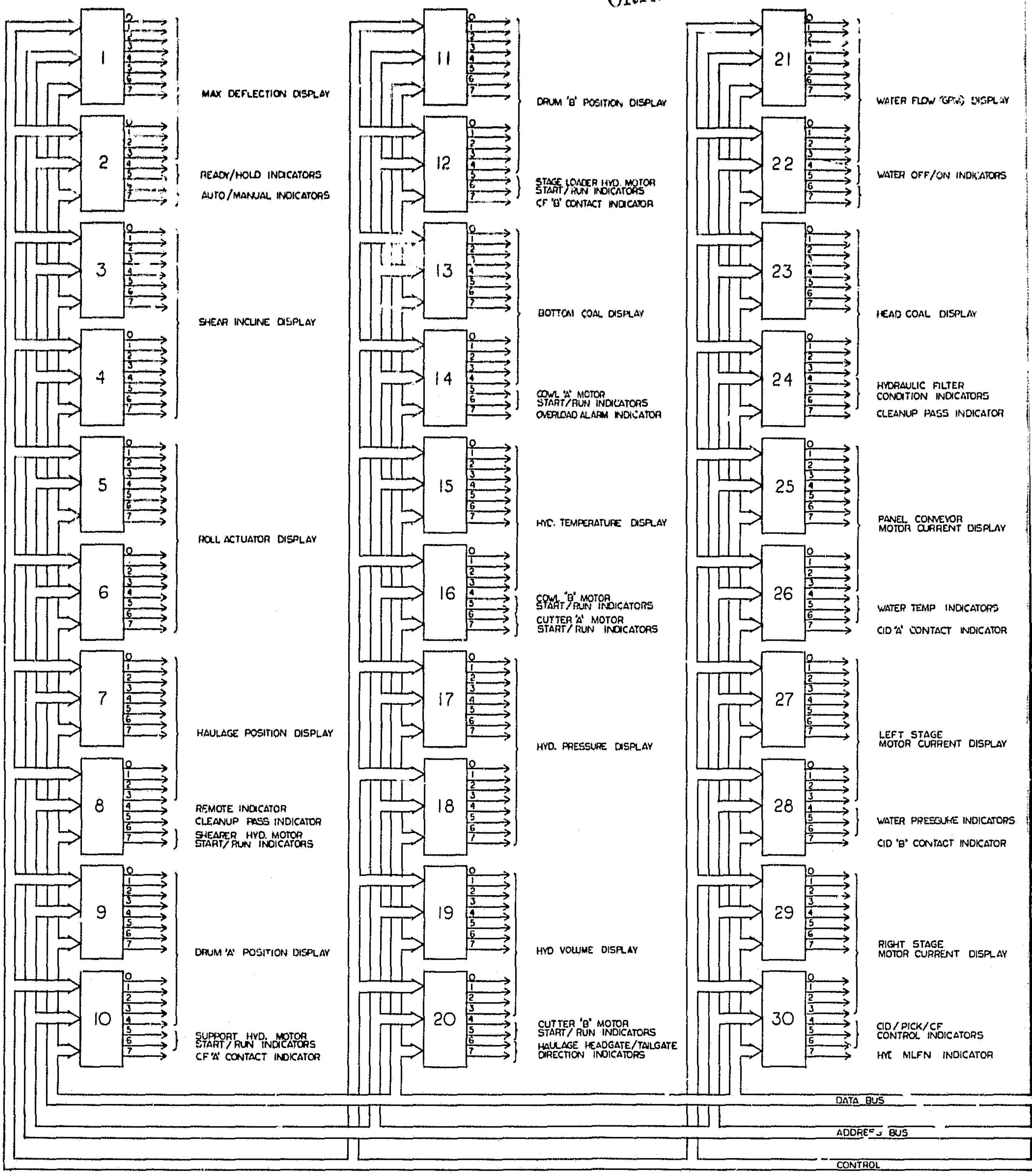

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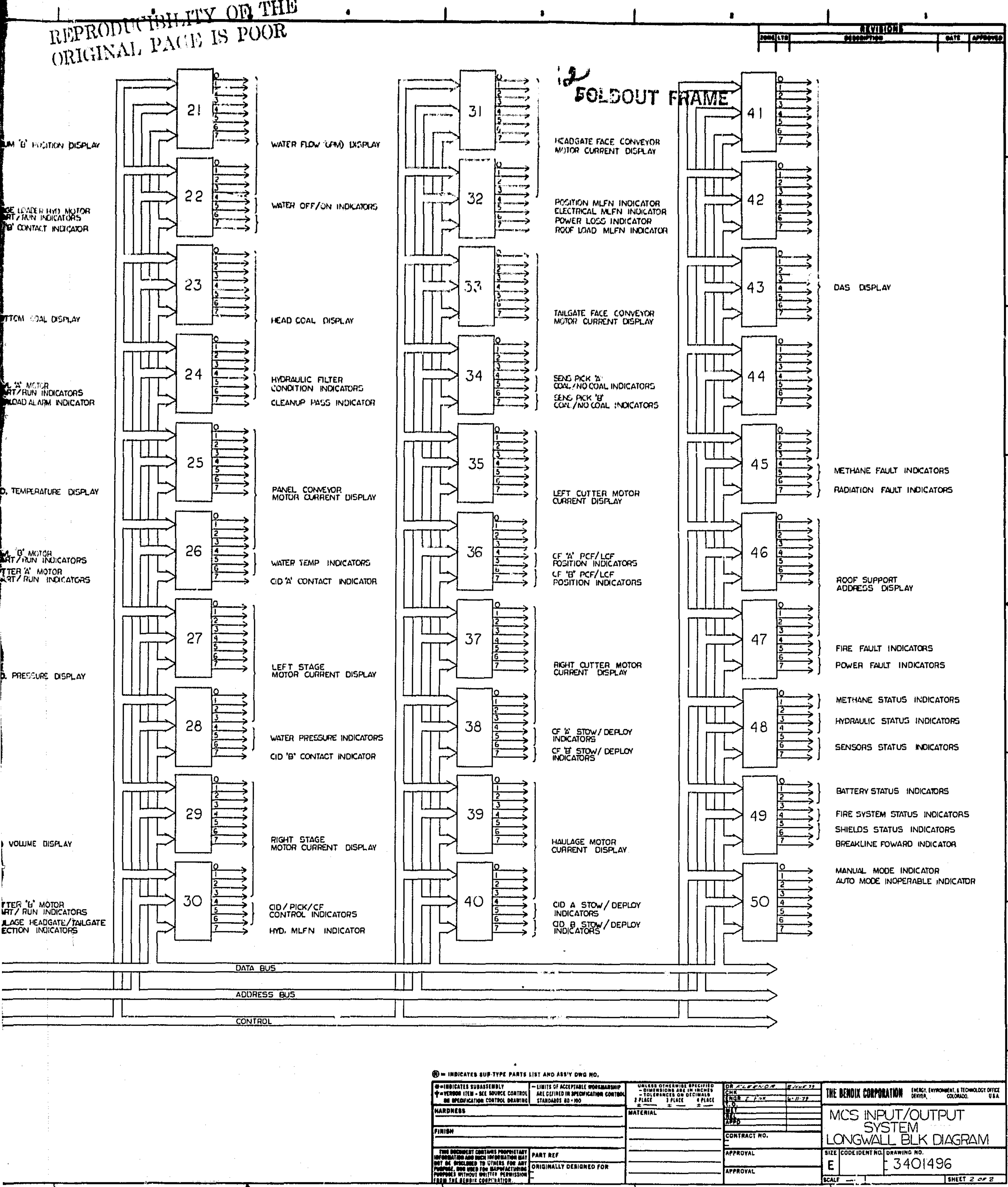

Figure 7-19. (Page 2 of 2)

for subsequent storage in the appropriate memory location within the random access memory of the microprocessor. This data is used by the computer in its algorithms or is transferred to the control and display console for visual presentation.

7.5.5.3 Communications; Reference Appendix A - The communications portion of the system is a micro-processor based subsystem employed to transfer voice and data from the MCS to and from the ECM and the roof support electronic subassemblies. This voice and data link also provides for the voice and data from the control and display console to the shearer and from the roof supports to the shearer.

The communications subassembly provides the mechanism for loading initial constants into the random access memory of the ECM processing and control computer. These constants are generated and stored in the processor located in the control and display console. The communications subsystem also provides the mechanism for interrogation of the shearer from the Master Control Station (MCS).

This communications subassembly is identical in all operating characteristics to the communications link described in the VCS report, Phase II Part I and interfaces directly to it. For convenience the description of its operating detail is enclosed in Appendix A of this report.

7.5.5.4 Central Processing - The MCS processing and control computer is a microprocessor based subassembly employed to provide the intelligence for remote check-out operation and interrogation of the shearer and roof support operations. This subassembly contains the control algorithms required for the remote check out and interrogation of the shearer and roof support systems.

The CPU strobes sensor or control data from the input/output ports for use, and also stores data for use by the control and display panel. Commands are loaded into ports of the input/output electronics for conditioning and subsequent use by control devices of

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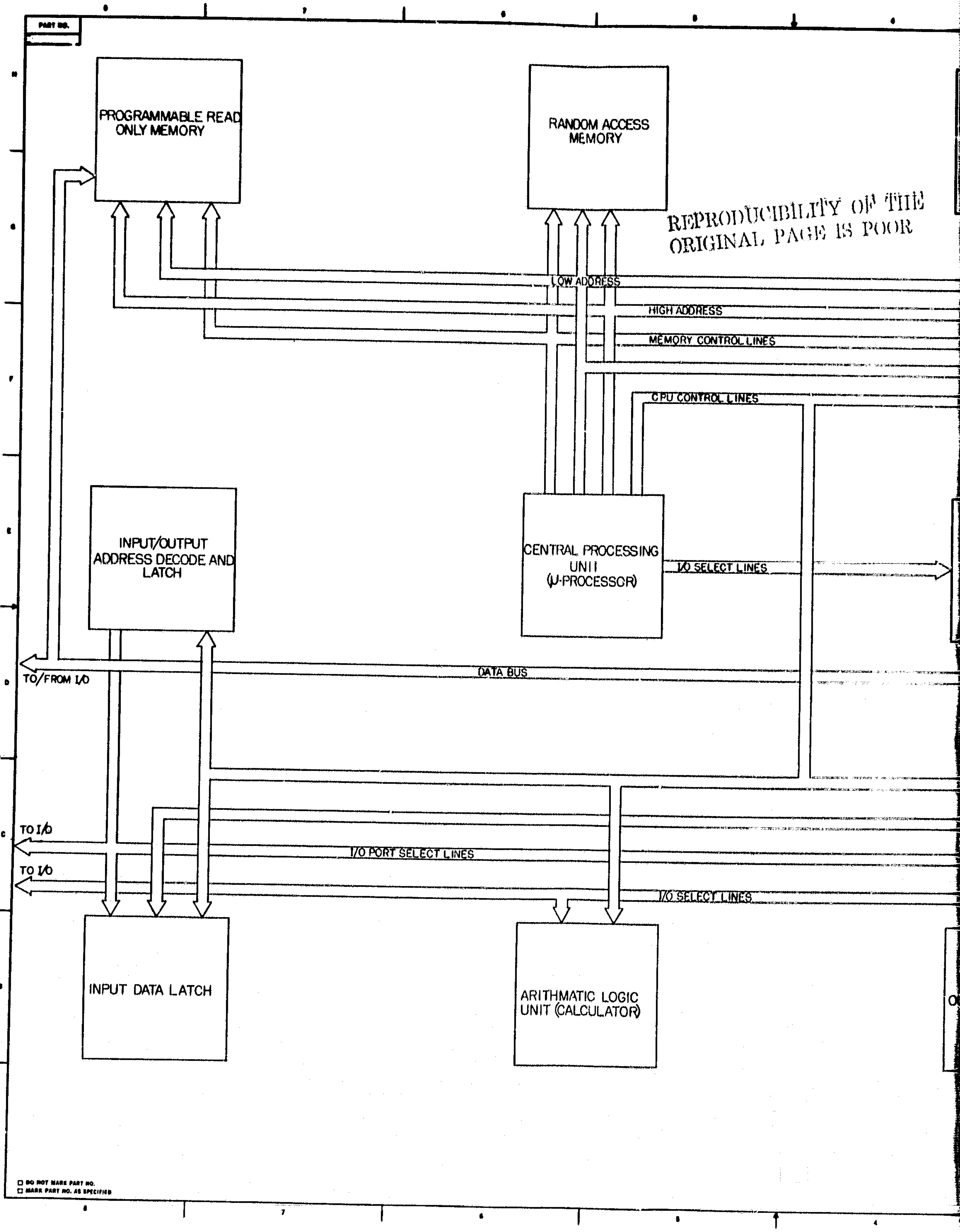

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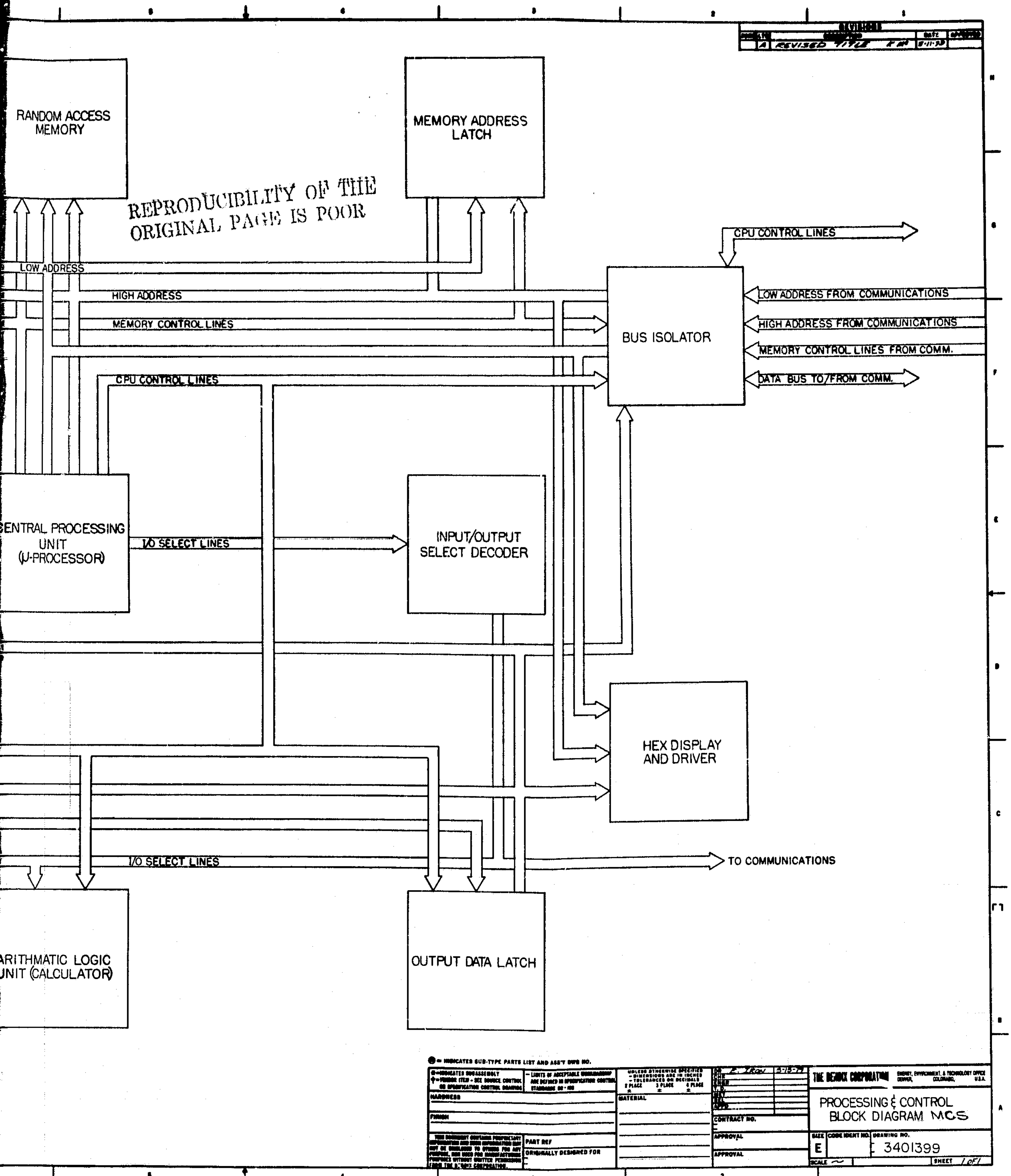

Figure 7-20.

shows the RAM that is required for the Main Processing and Control Computer. The MCS operation requires 5K bytes of RAM for storage of intermediate data and engineering evaluation data.

As with the other electronics within the MCS, the CMOS technology has been selected for the random access memory.

7.5.6.3 Programmable Read Only Memory (PROM) - The PROM employed within the subsystem is for permanent storage of the operational firmware, and constants, required by the CPU in its sequencing and computations. PROM was selected over Read Only Memory (ROM) because of the possibility of changes in the desired operation of the MCS.

At the time of this report there are no CMOS PROMS available so low power MOS devices were chosen which require a single power supply. These devices require relatively low power in the active state and may be powered down further when not being accessed.

7.5.6.4 I/O Select Decoder - The I/O select decoder is the decoding logic which decodes the microprocessor direct I/O select words into a single enable line, which represents the number described by that I/O select word. These lines are employed to select 8 input and output ports directly. These decode lines are employed to assist in the addressing of I/O ports, thereby extending the number of input/outputs which may be serviced.

7.5.6.5 I/O Address Decode and Latch - The I/O address decode and latch devices are latching decoders which will decode the memory address lines into discrete lines which represent the I/O device selected by the memory address lines. This technique is employed because of the numerious input ports which must be serviced.

CMOS technology has been chosen for use in these circuits.

7.5.6.6 The Arithmatic Logic Unit (ALU) (Calculator) - The ALU portion of the CPU electronics is employed for the solution of some of the equations used in the calibration of the CID. These equations

involve multiplication and division of floating point numbers and would require too much of the CPU time for a solution.

The CPU loads the input data latch with the numbers required for calculation. The CPU also provides the control lines required for the computation. The results of the computation is loaded into the output data latch where it may be stored or acted upon by the CPU.

Low power technology is employed in the ALU unit. CMOS technology will be employed in the hardware providing a satisfactory device is available at the time of the hardware build.

7.5.6.7 Input Data Latch - The input data latch is used to receive and store data from the CPU for use by the ALU in its computations of numbers. This device receives words from the CPU and latches the data.

CMOS technology is employed for these devices.

7.5.6.8 Output Data Latch - The output data latch is used to accept the answer from the computations performed by the ALU unit. This data latch stores the answers generated in the ALU until the CPU can read them into memory. Some consideration was given to disregarding the least significant bits of the answer because of their insignificance in the control. The decision to keep all bits was based on maintaining this capability for development evaluation, trend analysis, and system growth. The control for this latch comes from both the CPU and the ALU.

CMOS technology is employed for these devices.

7.5.6.9 Hex Display and Driver - The hex display is employed for trouble shooting. These devices are connected to the address and data bus lines to decode and display, in hexadecimal (0-F), the addresses and data on these lines. The Hex Display Driver is a CMOS device employed to decode the binary inputs and produce an output

drive to the specific segments of the Alphanumeric Display which represent that character. These devices, along with the Hex Display are mounted on one of the logic cards within the MCS.

7.5.6.10 Bus Isolator - The bus isolator is employed as an interface between the MCS process and control computer and the communications portion of the MCS electronics. The interface is required to connect the address and data bus lines between these two subsystems and allows the communications subsystem access to the MPCC memory. The communications subsystem reads memory for transmission to the ECM and Roof Support Electronics. The communications subsystem access to the Main Processor Control Computer (MPCC) memory also allows data to be transferred into this memory from the ECM and Roof Support Electronics.

The control for the bus isolator comes from MPCC control lines and are employed to start a hardware counter, open up the bus isolator and then halt to await a signal from the timer. The timer will restart the MPCC and close the bus isolator whereby both the MPCC and the communications processor will continue their independent routines, isolated from each other.

7.5.6.11 Power SupplyBox - The power supply box is an "explosion-proof" enclosure, mounted on the stage loader. This box contains all the DC power supplies required for the MCS system. All the heat dissipating transformers are mounted for optimum heat transfer through the walls of the power supply. The solid state devices that dissipate heat are mounted on custom fabricated heat sink brackets which, in turn, are mounted on the walls of the power supply box.

All the cables to/from the power supply box are routed through "explosion-proof" glands. The low voltage DC power supply cables are intrinsically safe, whereas the 120 VAC input cables must be "permissible" types.

7.5.7 Master Control Station Signal Conditioning - Figure 7-18, signal conditioning block diagram shows the electronic building

blocks required to interface all of the switches and sensors to the input ports and the various displays to the output ports. All the switches are located on the Control and Display Panel. The motor current and hydraulic pressure sensors are located in close proximity to the Master Control Station. All the displays consisting of incandescent lamps, light emitting diodes (LEDS), numeric and alphanumeric displays, are located on the MCS front panel.

7.5.7.1 Input Signals - All the input signals, consisting of switches and sensors, can be characterized as follows:

Momentary Switches - The Control and Display panel contains a wide variety of momentary switches; toggle, pushbutton and keyboard types. The purpose of these switches is to send a message to the input ports, whether command or data. The toggle and pushbutton switches interface to the Input Ports via anti-bounce circuits and data latches. The anti-bounce circuits recognize only the first switch closure and ignores all other multiple bounces associated with mechanical switches. Since the switches are momentary, the data latches "store" the switch closure until the computer resets them.

Thumbwheel Switches - The Control and Display panel contains a number of binary coded decimal (BCD) thumbwheel switches. These switches are used to enter data into the computer through the Input Ports. Each switch output consists of 4 bits, therefore, some functions comprised of 4 switches will require 16 bits for processing. Those lines (bits) are conditioned through anti-bounce circuits and data latches.

Keyboard Switches - There are two (2) keyboard matrices on the Control and Display panel, used for entry of control and parametric data into the MCS process and control computer for transfer to the ECM. These keyboard switches consist of an X-Y matrix that needs to be encoded. A sixteen (16) key encoder is used to interface the data from the keyboard to data latches. The latches, in turn, route

the data lines to the Input Ports.

Current Sensors - Five (5) current transducers (sensors) are used to monitor various motor currents, to ensure proper and safe operation. These motors are for the panel conveyor, stage loader (2), and the system headgate and tailgate face , ,or. The current sensed by the transducer is converted to voltage pro,.ortional to that current and then further converted to digital data by an eight (8) bit analog to digital converter. The data is then latched for the Input Ports.

Other Sensors - In addition to all the switches and sensors above, there are transducers associated with the roof support hydraulics that yield an analog voltage signal proportional to certain hydraulic conditions. Prior to being digitized by an analog to digital converter, the signal is buffered to acceptable levels and loading conditions. The digital data out of the A/D converter is routed to the Input Ports by way of data latches.

7.5.7.2 Output Signals - The output ports of the MCS are primarily used to provide display signals. These signals are routed to the Control and Display panel of the MCS via conditioning electronics.

Indicators - The signal conditioning electronics interfaces that process the various indicators, are basically identical. The signal from the output port is buffered to prevent overloading the ports and to obtain proper voltage levels for the next electronic building block. The signal out of the buffer is then used to energize either a lamp, LED or magnetic display driver circuit.

Displays - The numeric and alphanumeric displays are also buffered from the output ports and converted to 7 bits or 16 bits of data by BCD to 7 segment and BCD to 16 segment decoders, respectively. The data bits, then energize proper display drivers.

7.6 MCS Mechanical Design - The MCS console is shown in Figure 7-7 The frame is structurally independent of the skin to facilitate

assembly and maintenance procedures. The skin is sheet metal attached to the frame by socket head cap machine screws. A gasket is provided for dust seal. Mounting pads are provided to attach to a bracket to be welded to the stage loader.

7.6.1 Electronic Packaging Design - The card rack is a Mupac 13 position card cage selected to withstand low frequency vibration. Access to the cards is through the removable side panels of the console. The controls and displays are protected by magnetically latched lexan double doors which allow monitoring of the status indicators with the doors closed. The emergency off switch is accessible through a cut-out. The panel face is removable; wire length routing allows access to connectors such that the panel can be removed for servicing.

The control lines are routed through the bottom of the console to allow transport of the console with the mounting surface down.

The overhead lamp is replaceable from the front and protected by the pull out drawer in which it is mounted.

7.6.2 MCS Mounting Technique - The MCS console is mounted to the stage loader as shown in Figure 7-1. The mounting location allows use by a standing operator such that all controls are easily reached and all displays are visible. The power supply is also mounted to the stage loader in close proximity.

7.7 MCS Lighting Design - Illumination of controls and displays is provided by internal illumination and external illumination. The external illumination is provided by an overhead lamp mounted in a pull-out compartment. The lower lip of the compartment is located below the eye level of the standing operator to prevent direct glare. Indirect glare is relieved by allowing the lamp to be extended a variable distance so the operator can adjust the direction of the light relative to his height viewing distance and the surfaces of the components. In general, the best illumination is provided

by moving the lamp forward to about half the viewing distance.

This mounting method allows lamp and compartment to be stowed on line with the console face. With the lamp extended and the cover doors open, the operator work area is delineated and the operator's attention focused on the panel surface. Under anticipated conditions of use, all legends on internally illuminated switch/indicators will be readable whether illuminated internally or not because of the overhead lamp.

8. POWER SUPPLY DESIGN

The Power Supply Block diagram is presented in Figure 8-1. Primary 120 VAC 60 Hz power is obtained from a power panel on the stage loader and fused at 5.0 amps. Since this primary AC voltage is susceptible to extreme fluctuations, of up to 50% of nominal, an AC voltage regulator is incorporated. The AC output of the voltage regulator energized four (4) power supplied: 5 VDC/75 Amps, + 12 VDC/-2 Amps, - 12 VDC/2 Amps, and + 28 VDC/ 1 Amp.

The circuits which the regulated power supplies energize are protected by overvoltage devices. Should the supply voltages surge to an unsafe level, due to a malfunction, the overvoltage protectors will clamp the outputs to near zero volts, thus protecting the associated circuits from damage. Each supply is redunduntly current limited thus yielding "intrinsically safe" power out of the power supply box.

8.1 Power Supply Requirements - Estimates of the MCS and YAS power requirements supplied by the MCS power supply were based on past experience with systems of similar complexity. These estimates are as follows:

1. + 5 VDC at 60 amps
2. + 12 VDC at 0.90 amps
3. - 12 VDC at 0.90 amps
4. + 28 VDC at 0.30 amps

These power lines are made intrinsically safe by redundantly limiting the current levels and routing them from the power supply box through an explosion proof gland and MSHA approved cable. The power limits are as follows:

1. + 5 VDC - Fifteen power lines are required each of which are redundantly current limited to 4.0 amps. Each line is further constrained such that its inductive load shall not exceed 1 microhenry and its capacitive load shall not

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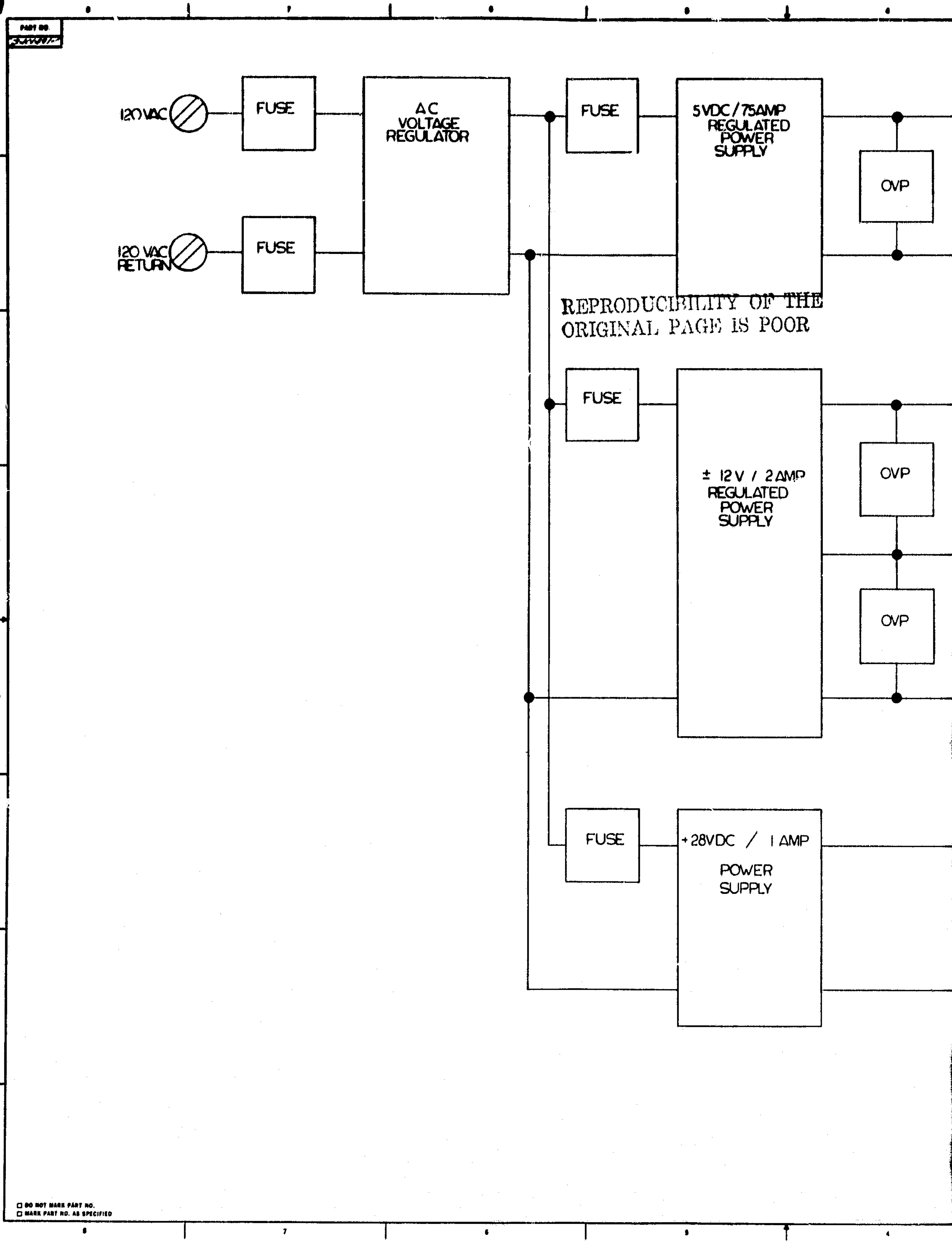

2 FOLDOUT FRAME

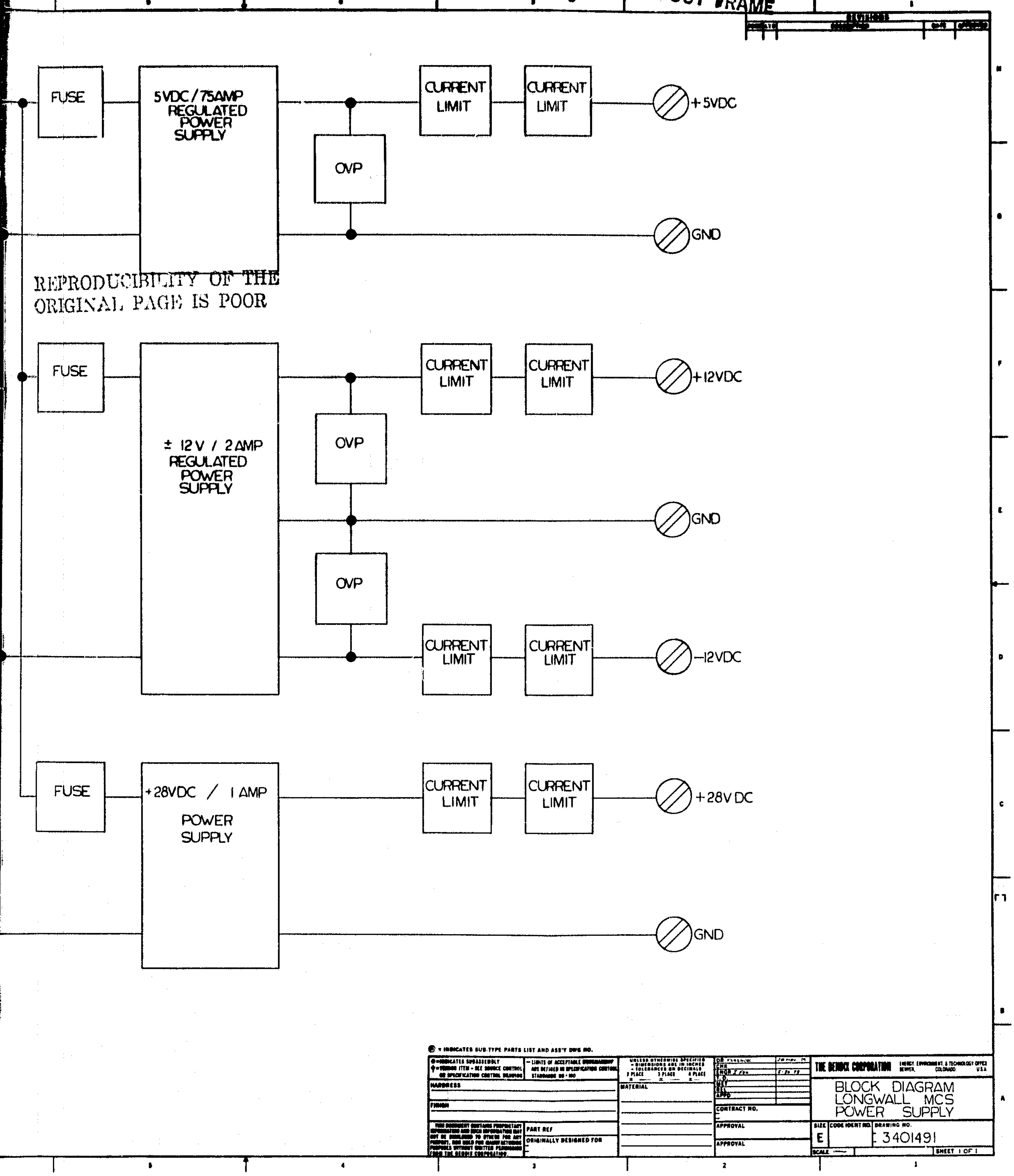

Figure 8-1

exceed 1000 microfarad. These levels are significantly below the 6 amp level at 5 volts specified for intrinsic safety by the SMRE Research Report titled "Some Aspects of the Design of Intrinsically Safe Circuits" published by the Minority of Power Safety in Mines Research Establishment, Red Hill, Off Broad Lane, Sheffield 3, England

2. + 12 VDC - Nine power lines are required, each of which is redundantly current limited to 0.10 amps. Each line is further constrained such that its inductive load shall not exceed 5 milihenry and its capacitve load shall not exceed 0.5 microfarad. These levels are significantly below the 0.15 amp level at 24 volts (± 12) specified for intrinsic safety by the SMRE Research Report quoted above.

3. - 12 VDC - Nine power lines are required, each of which is redundantly current limited to 0.10 amps. Each line is further constrained such that its inductive load shall not exceed 5 milihenry and its capacitive load shall not exceed 0.5 microfarad. These levels are significantly below the 0.15 amp level at 24 volts (± 12V) specified for intrinsic safety by the SMRE Research Report quoted above.

4. + 28 VDC - 3 power lines are required, each of which is redundantly current limited to 0.10 amps. Each line is further constrained such that its inductive load shall not exceed 5 milihenry and its capacitive load shall not exceed 0.5 microfarad. These levels are significantly below the 0.13 amp level at 28 volts specified for intrinsic safety by the SMRE Research Report quoted above.

8.2 Power Supply Distribution - Figure 8-2 shows the distribution of the various supplies to the MCS and YAS circuits. The + 5 VDC supply is used to energize all the circuits in the MCS and YAS roof support mounted electronics. In addition to the + 5 VDC supply, the A/D converters in the MCS and YAS roof support electronics re-

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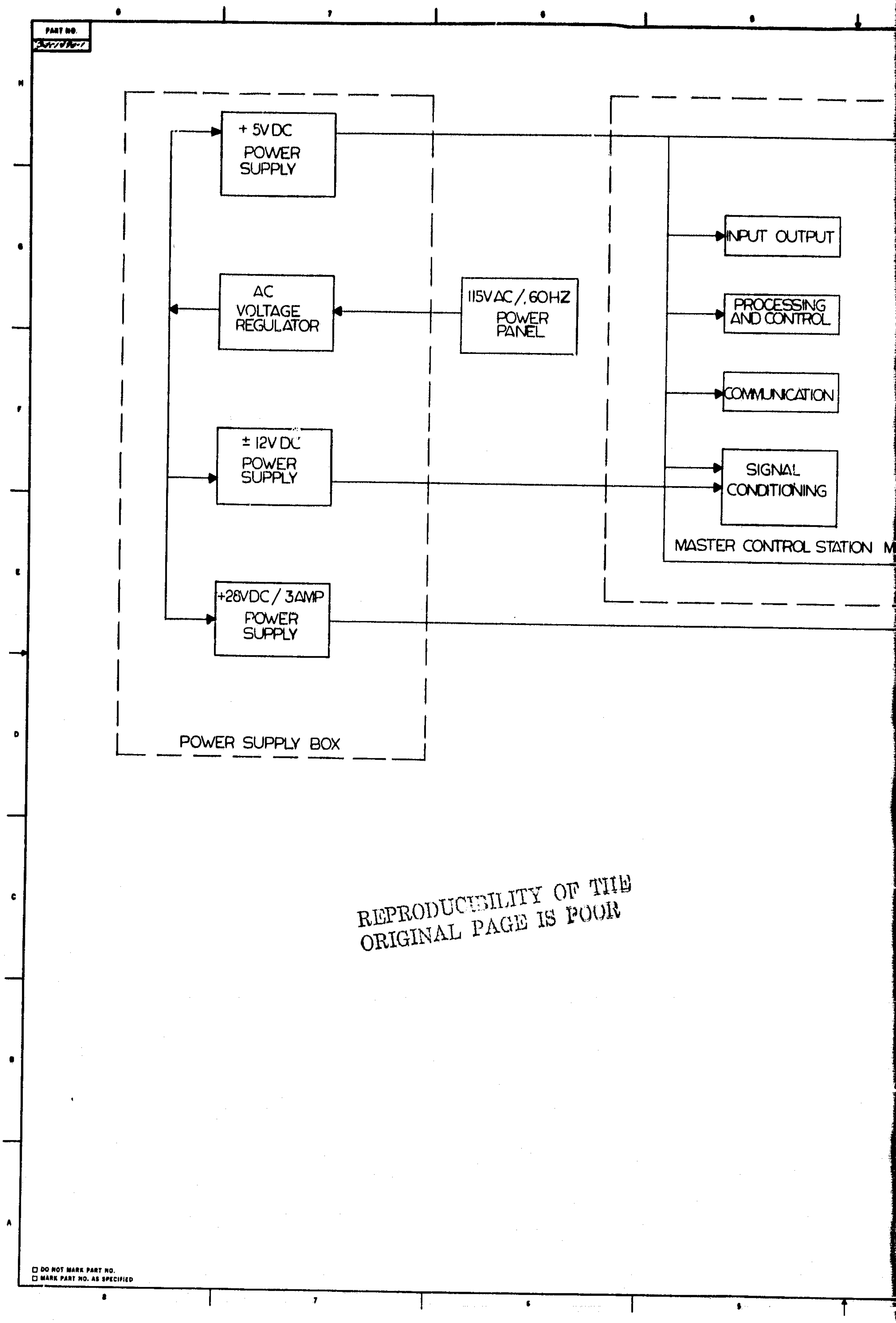

2 FOLDOUT FRAME

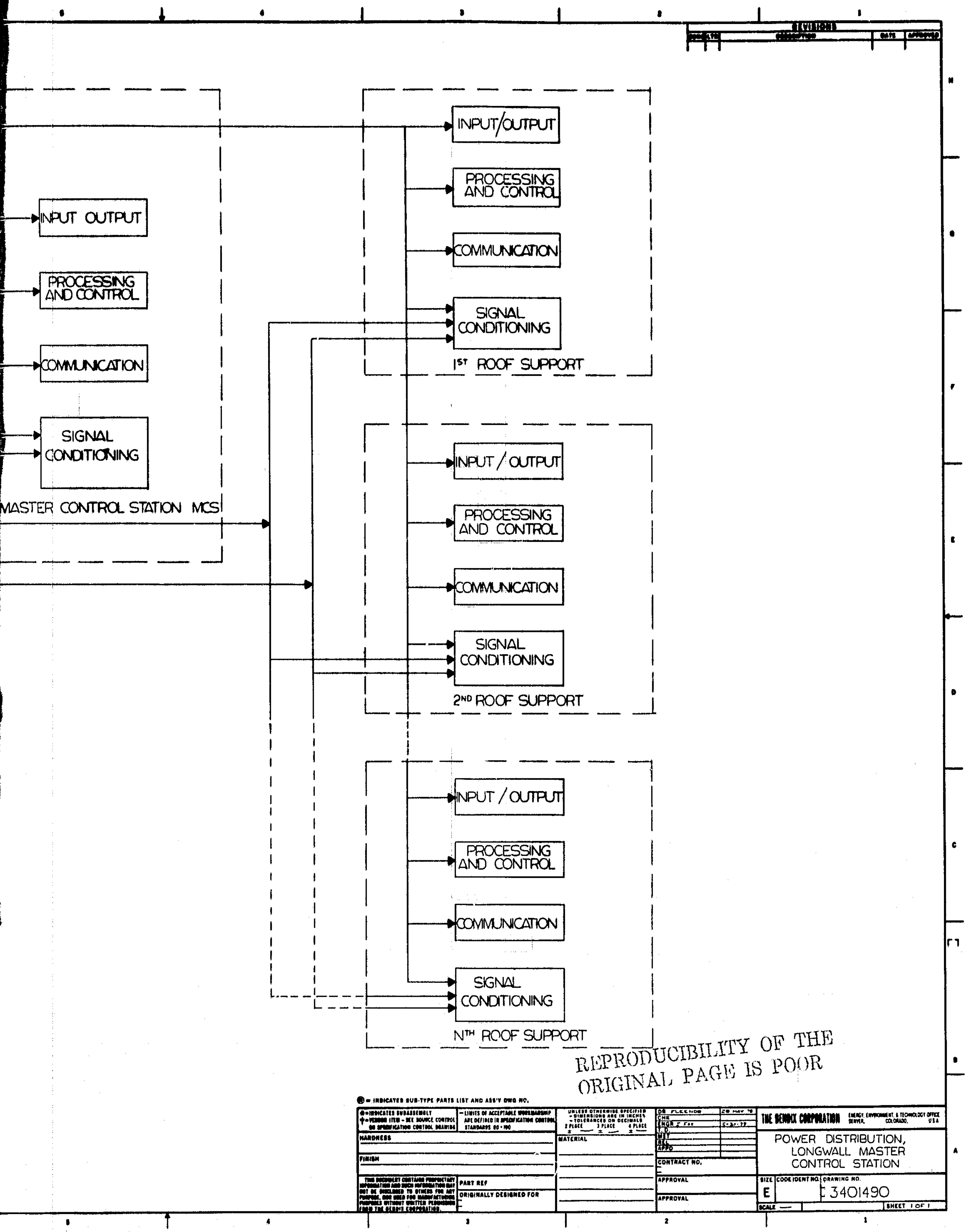

Figure 8-2

quire $\pm$ 12 VDC. The + 28 VDC is strictly used for energizing solenoids in the roof supports via signal conditioning circuits.

8.3 <u>Fabrication of MCS Power Supply Box</u> - The power supply box is an "explosion-proof" enclosure. This box contains all the DC power supplies required for the MCS and YAS. All the heat dissipating transformers are mounted for optimum heat transfer through the walls of the power supply. The solid state devices that dissipate heat are mounted on custom fabricated heat sink brackets which, in turn, are mounted to the walls of the power supply box.

All the cables to/from the power supply box are routed through "explosion-proof" glands. See Figure 8-2, Longwall MCS Power Distribution Block Diagram. The low voltage DC power supply cables are intrinsically safe.

The power supply box with approximate dimensions of 14 x 24 x 9 inches is located on the stage loader as shown in Figure 7-1. There are three (3) cables emerging out of explosion-proof glands; AC power input cable, roof support cable, and MCS electronics cable.

APPENDIX A

The following Appendix we extracted from the Final Report titled "Automated Longwall Guidance and Control System, Phase II, Part I Vertical Control System", issued on April 5, 1979. This Appendix is included as a convenience to the reader since all of the discussions on ECM communications applies to the MCS and Yaw Alignment System.

The only significant changes, since Phase II Part I Report was issued, are changes of data messages between the subsystems (ECM, MCS and Roof Supports). These changes are reflected in Tables 4-6 through 4-10, listing the various messages and bit numbers.

Although the total transmission time for the system was increased by the above changes. The Communications Timing portion of the Appendix is not affected since original design configuration made allowance for future expansion. As discussed in Paragraph 4.4.5 and shown in Figure 4-22, a cycle time of 3.0 milliseconds was reserved for growth which can accomodate the additions made.

4.4 Design of Communications Subsystem - The longwall automatic control system has interdependent subsystems separated by distances of 1200 feet or more. This interdependency requires communications be provided for voice and data between these integrated subsystems. A radio link would be preferred, from a mobility standpoint, but because of expense and communications reliability problems associated with the severe environment at the coal face, a cable link was selected for communications.

Information and control can be transmitted on a single line by using serial digital data between subsystems. A coax transmission line will be used to allow high data rates and to provide shielding from the high radio frequency interference environment caused by large electric motors in the area.

As a supplement to the normal longwall voice communication system already present in the mine, a voice channel will also be maintained via the ECM electronics. This is done as a convenience for shearer maintenance, checkout, calibration and turn around. Voice communications may be carried on the same coax line that is used for digital data by using a separate carrier frequency. The digital data will be represented on the coax line as two discrete frequencies. A frequency shift keyed modulation is used to cause one frequency to be transmitted for a high (or one) bit, and a different frequency to be transmitted for a low (or zero) bit. Frequency shift keying (FSK) is employed to increase noise immunity on the long coax communications line. Control digital data is sent directly to an FSK modulator, and analog voice data is converted to digital form before it is also sent through an FSK modulator and then combined with the control data to be amplified and sent out on a communications line.

4.4.1 ECM Communications Block Diagram - Figure 4-21 shows a block diagram of the major components that compose the shearer communications system. Digital data is manipulated by a microprocessor unit that is dedicated to communications only. Associated with the Communications Processor Unit are Random Access Memory (RAM), Programmed Read Only Memory (PROM), and a memory address latch that is required to expand the addressing capability of the 8 bit bus to 16 bits (increases capacity to 65,536 locations).

Other portions of the longwall communications system will have the same type of communications interface. To receive data from the other units requires accurate synchronization of all transmit/receive operations. A master clock will be located at the MCS to supply a clock signal to the coax transmission line. An active filter tuned to the clock frequency will receive the clock signal and amplify it for use as an internal clock for all communications control functions.

PART NO.

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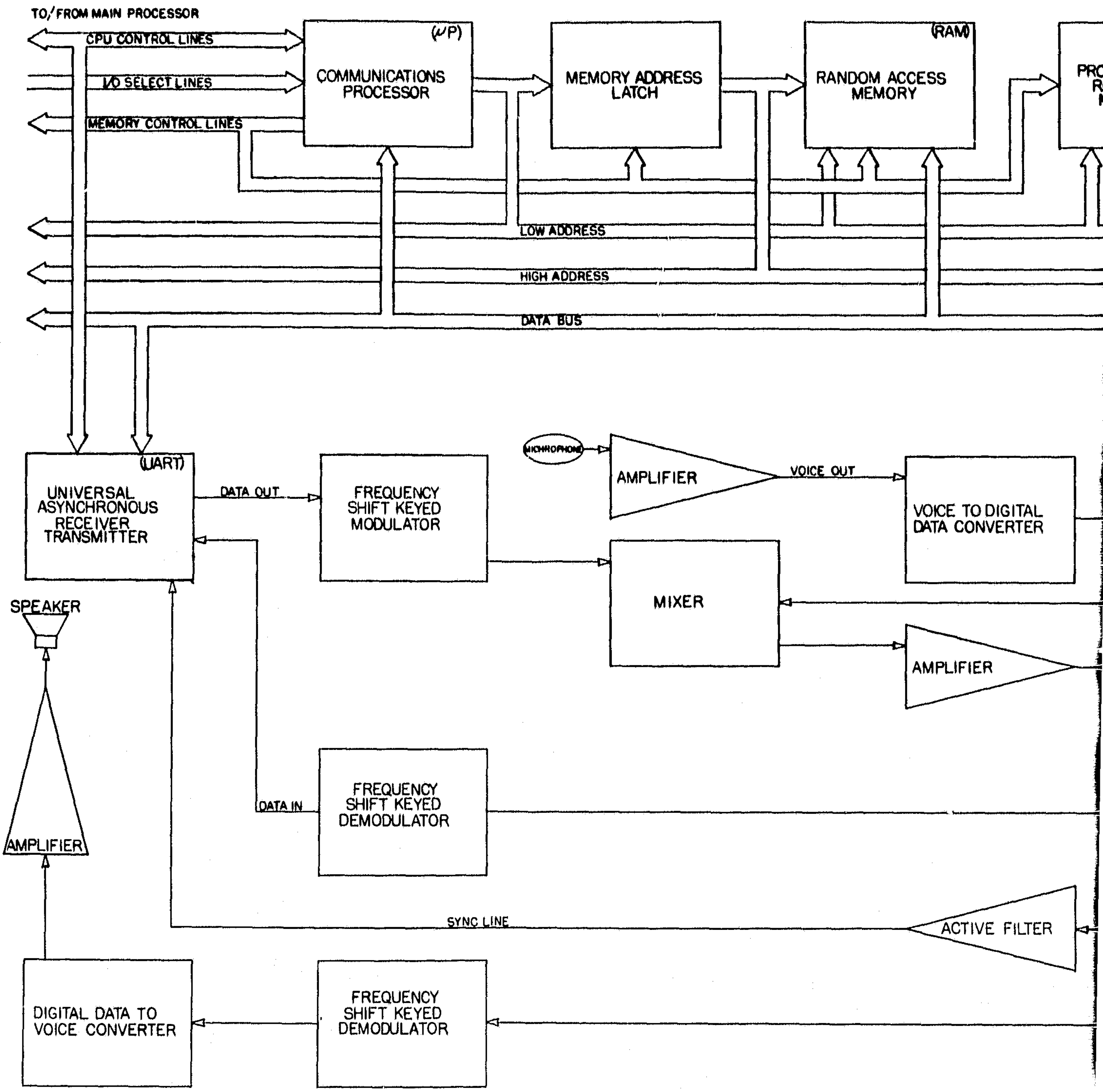

☐ DO NOT MARK PART NO.
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HARDNESS

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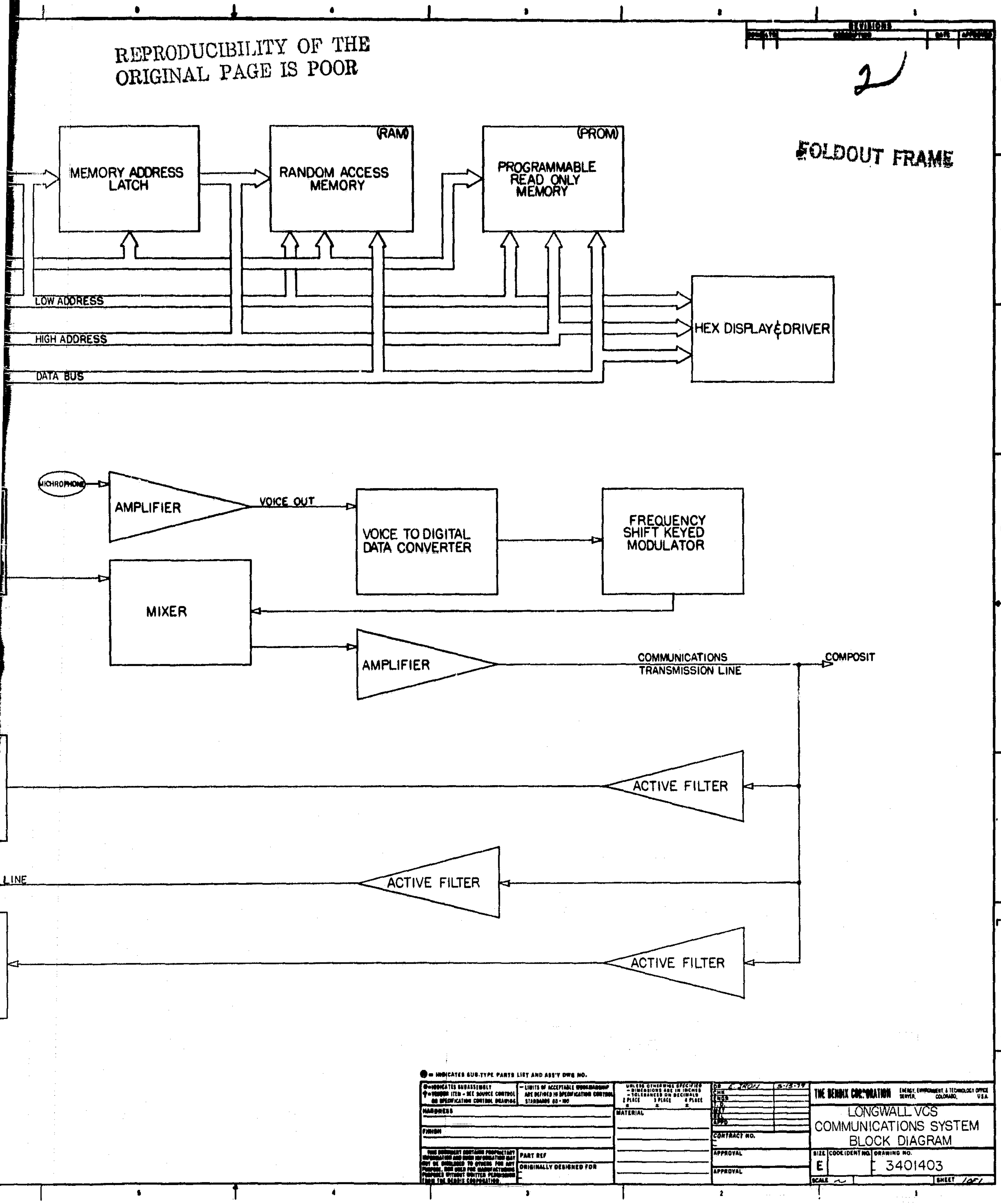

(RAM)
(PROM)
MEMORY ADDRESS LATCH
RANDOM ACCESS MEMORY
PROGRAMMABLE READ ONLY MEMORY
LOW ADDRESS
HIGH ADDRESS
DATA BUS
HEX DISPLAY & DRIVER
MICROPHONE
AMPLIFIER
VOICE OUT
VOICE TO DIGITAL DATA CONVERTER
FREQUENCY SHIFT KEYED MODULATOR
MIXER
AMPLIFIER
COMMUNICATIONS TRANSMISSION LINE
COMPOSIT
ACTIVE FILTER
ACTIVE FILTER
ACTIVE FILTER
LINE
THE BENDIX CORPORATION
LONGWALL VCS
COMMUNICATIONS SYSTEM
BLOCK DIAGRAM
E
3401403

Figure 4-21

4.4.2 Communications Inputs - The ECM contains the control algorithms to operate the longwall shearer automatically. The automation requires data input from the MCS and the roof support electronic systems to perform its functions properly. Master controls such as initialize, auto start, set seam height, select top coal thickness, calibrate sensors and set shearer traverse speed are obtained from the MCS control panel. Status of the roof support system is also required by the shearer so that conveyor and roof support advance can be controlled properly in relation to the shearer movement in the automatic sequence. Data received from the control and display panel and the roof supports are listed in Tables 4-6 and 4-7.

The discrete command and status information is represented by 8 bit words or combined to form 8 bit words. Table 4-6 lists the command and status words from the MCS to the ECM where the 8 bit words are sent complete and 4 of the 2 bit words are combined to form 8 bit words for transmission. Each of these message sequences are preceded by two 8 bit words. The first word is a message start signal composed of all one bits; the second word is an identification word whose first 4 bits indicate the desired destination of the message, and the last 4 bits indicate where the message originated. There are then 8 words of message plus 2 words of message start coding for a total message length of 10 words or 80 bits.

The roof support to shearer message information list is given in Table 4-7. After combining messages where possible, there are 6 words of data required for each roof support. It is now planned to send 6 shield data sets per communication cycle, so that 36 words will be sent in sequence. Adding the two words of start code for this message results in a total message length of 38 words or 304 bits.

The messages described above are received in serial form from the communications transmission line. An active filter will receive the data bits. This data is converted in the frequency shift keyed demodulator to an NRZ data representation, which is then shifted into the Universal Asynchronous Receiver Transmitter (UART). When 8 bits have been received, a word is transferred in parallel to the communications processor data bus where the data is stripped out and then stored in appropriate memory locations. Input and output operations at the UART are controlled by the communications processor.

4.4.3 Communications Outputs - The ECM output consists of status information sent to the MCS and commands to the Roof Support Electronics System. The message format is the same for all messages in the communications loop. There is one start word and one identification word, followed by as many 8 bit words as needed to complete the message. A list of the information sent from the ECM to the MCS is presented in Table 4-8.

Table 4-6. MCS to ECM Messages

Message Description	Number of Bits
Control Power On/Off	2
Manual, Automatic, or Automatic Remote Manual Control	2
Drum Cutter Motor A Control	2
Drum Cutter Motor B Control	2
Haulage Motor Direction	2
Haulage Motor Speed	8
Ranging Arm A Extend/Retract Command	2
Ranging Arm B Extend/Retract Command	2
Pump Motor On/Off	2
Cut Follower A Deploy/Stow Command	2
Cut Follower B Deploy/Stow Command	2
CID A Deploy/Stow Command	2
CID B Deploy/Stow Command	2
Cowl A Control	2
Cowl B Control	2
Roll RAM Extend/Retract Command	2
Sensitized Pick Setting	12
Coal Thickness Setting	12
Request Data Address (DAS)	8

Table 4-7. Roof Supports to Shearer Messages

Message Description	Number of Bits
Roof Support Address (1 to 150)	8
Control Power On/Off	2
Vertical Ram Status	4
Horizontal Ram Status	2
Roof Support Load (Pressure)	2
Vertical Ram Position	8
Horizontal Ram Postiion	8
Hydraulic Pressure Status	8
Canopy Extension Status	2

Table 4-8. ECM to MCS Message

Message Description	Number of Bits
Manual, Automatic, or Remote Manual	2
Control Power On/Off	2
Pump-Shearer On/Off	2
Hydraulic Pressure	2
Cowl A Position	2
Cowl B Position	2
Haulage Motor Direction	2
Hydraulic Filter Pressure Drop Limit	2
Methane Level	8
Water Flow	8
Drum B Current	8
Drum A Current	8
Haulage Motor Current	8
Cut Follower A Position	8
Cut Follower B Position	8
Coal Interface Detector Position	8
Coal Thickness Setting	8
CID Output (Coal Thickness)	8
Ranging Arm A Position	8
Ranging Arm B Position	8
Inclinometer Output	10
Cut Follower A Deployed	2
Cut Follower B Deployed	2
Sensitized Pick Level	8
Oil Level Sensor	8
Radiation Level Sensor	8
CID A Status	4
CID B Status	4
Data Addressed from DAS	8
Addressed Data Output	8
Hydraulic Volume Status	4
Hydraulic Filter Status	4

After combining data where convenient, there are 22 8 bit words or bytes of information, plus the two leading bytes for a total of 24 bytes.

A list of the commands sent from the ECM to the Roof Supports Electronics is presented in Table 4-9. The total number of bytes for one message is 20, composed of two leading bytes, and 6 sets of 3 bytes that are sent to 6 different Roof Support Electronic units. This is done by making the first byte of a set of 3 bytes be the address of the particular roof support for which the commands are intended. To completely command all 150 roof supports requires 25 communications cycles, since only 6 are addressed per cycle. Since one cycle now requires 25 milliseconds, all roof supports are commanded once per .025 sec. x 25 = 0.625 sec. This seemed adaquate for this VCS preliminary design but may be altered when the YAW alignment system is completed.

4.4.4 Other Communications - In order to size the communications time cycle, the other two links that do not involve the ECM are also included here. The MCS may command the roof supports electronics directly, and the roof supports electronics send status information directly to the MCS.

Table 4-10 presents the roof supports to control and display message, and Table 4-11 presents the control and display to roof support message. Combining data into packed bytes and adding the leading words for each message sequence results in a total of 8 bytes for each of the messages between roof supports and the control and display panel.

4.4.5 Communications Timing - To integrate the various communications subsystems, a communications cycle was defined which provides for the proper timing of transmitting and receiving information for each unit on the communications line. There are three basic subsystems in the overall system: the ECM, the MCS, and Roof Support Electronics (RSE). Each of the three subsystems sends one message to each of the other two subsystems once per communications cycle. To obtain the time required per cycle, the total message length and bit rate must be defined.

The limiting factor in determining bit rate results from the frequency shift keyed (FSK) modulator. The upper frequency recommended for the selected unit is 500 KHz. The bit rate should be about a factor of 10 lower to provide at least 10 cycles of the carrier in one bit time. The bit rate selected is 40 K bits/sec. The clock frequency of a UART must be set at 16 times the bit rate, or 640 KHz. The master clock on the C&D panel which coordinates the communications is therefore set to 640 KHz. With a bit rate of 40 K bits/sec, the 8 bit word (or byte) rate is 5000/sec.

Table 4-9. ECM to Roof Support Electronics Message

Message Description	Number of Bits
K + h Roof Support Address (1 through 256)	8
Conveyor Advance Amount	8
Advance Conveyor Command	2
Advance Roof Support Command	2
K + 1 Roof Support Address (1 through 256)	8
Conveyor Advance Amount	8
Advance Conveyor Command	2
Advance Roof Support Command	2
K + 2 Roof Support Address (1 through 256)	8
Conveyor Advance Amount	8
Advance Conveyor Command	2
Advance Roof Support Command	2
K + 3 Roof Support Address (1 through 256)	8
Conveyor Advance Amount	8
Advance Conveyor Command	2
Advance Roof Support Command	2
K + 4 Roof Support Address (1 through 256)	8
Conveyor Advance Amount	8
Advance Conveyor Command	2
Advance Roof Support Command	2
K + 5 Roof Support Address (1 through 256)	8
Conveyor Advance Amount	8
Advance Conveyor Command	2
Advance Roof Support Command	2

Table 4-10. Roof Supports to Control and Display Panel Message

Message Description	Number of Bits
Roof Support Address (Per DAS Request)	8
Control Power On/Off	2
Manual/Auto Status	2
Vertical Ram Drive	2
Horizontal Ram Drive	2
Roof Support Load	2
Vertical Ram Position	8
Horizontal Ram Position	8
Hydraulic Pressure	8

Table 4-11. Control and Display Panel to Roof Supports Message

Message Description	Number of Bits
Roof Support Address	8
Manual, Automatic or Remote Manual	2
Vertical Ram Extend/Retract Command	2
Horizontal Ram Extend/Retract Command	2
Conveyor Advance Amount	8
Advance Conveyor Command	2
Advance Roof Support Command	2
Data Request Roof Support Address (DAS)	8
Sensor Address (DAS)	8

To define the total communications cycle, each of the six messages between subsystems was defined to determine message lengths as shown in Table 4-12 below.

Table 4-12. Communications Message Lengths

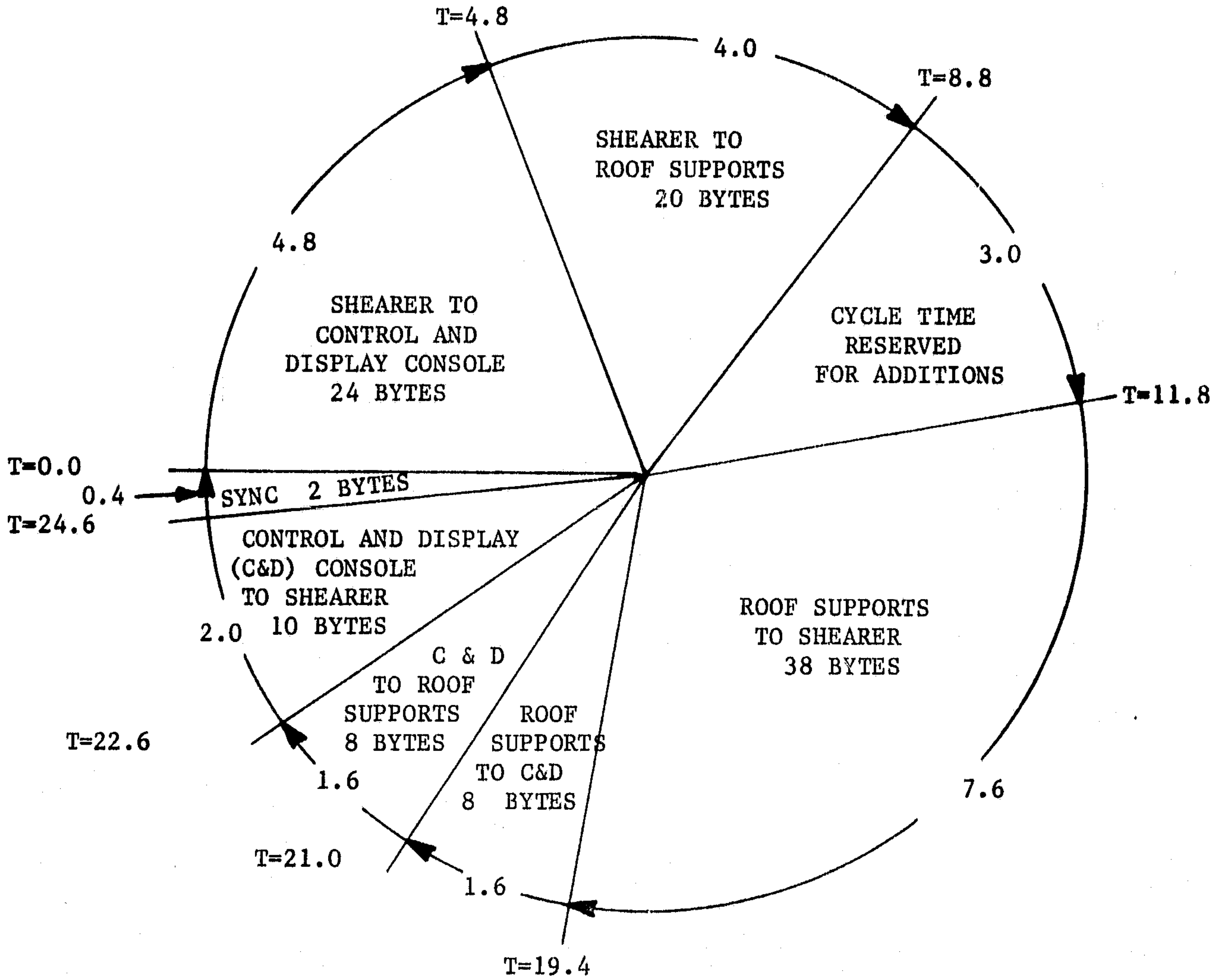
Message Description	Number of Bytes
Shearer to Control and Display	24
Shearer to Roof Supports	20
Roof Supports to Shearer	38
Roof Supports to Control and Display	8
Control and Display to Roof Supports	8
Control and Display to Shearer	10
Control and Display Sync Words	2
Total	110

Transmitting a total of 110 bytes at 5000 bytes/sec means that the minimum time for one cycle is 110/5000 = 0.0220 sec, or 22.0 milliseconds. To allow for some expansion in the event that some additional data needs to be transmitted, a cycle time of 25 msec was selected. Figure 4-22 shows the present definition of one complete cycle, including 3.0 milliseconds of off-time that is reserved for expansion.

The communications cycle is initialized by the MCS transmitter, which sends out 2 sync words on the transmission line and resets an internal counter. Each communications system on the line will use the sync words to reset their own internal counter to establish when their own transmission is to occur in the communications cycle. The MCS communications will then repeat the sync words every 25 milliseconds, using the master clock frequency and its internal counter. As the communications cycle is now defined, the two sync words will be transmitted immediately following the MCS to shearer message.

4.4.6 ECM Communications Processing - A block diagram of the functional flow that takes place in the ECM communications microprocessors is presented in Figure 4-23. The operations that are performed have been separated into 6 basic routines. Two of the routines deliver data words to be transmitted and read data words from the receiver electronics. The other four routines manipulate data between memory locations, format words for transmission, and strip out data from words received.

Each of the routines has two entry points, one for the initial entry in which initialization of that routine takes place, and a second entry point for all subsequent entries until that routine is



NOTE: TIME ARE IN MILLISECONDS (MS), AND ONE COMPLETE CYCLE=25MS

Figure 4-22. Serial Data Line Timing Cycle

completed. Thus, the transmitter routine has initialization entry point designated by 1 and subsequent entries enter at 2. Similarly, the other routines are entered initially at numbers 3, 5, 7, 9 and 11, and second and all subsequent entries into routines use numbers 4, 6, 8, 10, and 12 until the particular routine is satisfied. The variable TR is used throughout to cause return to either transmit or receive routines so it is set equal to 1 through 4. The variable F is used to cause return to the data manipulating routines and takes on values 5 through 12.

The communications processor is capable of operating at a higher rate than the input/output device, which is a Universal Asynchronous Receiver Transmitter (UART). The UART takes 8 bits of parallel data and shifts it out serially for transmission, and receives serial data, shifting it into an 8 bit register where it is then read in parallel by the communications processor. At the serial bit rate chosen (40 K bits/sec), the communications processor can perform approximately 90 program executions during the time that one 8 bit word (byte) is being received or transmitted. The operational flow is thus structured to loop through the manipulative functions continuously, with a test provided within all loops that checks whether a transmit or receive operation is due. After a transmit or receive request comes on, it is sufficient to assure that the request be answered before about 90 additional program steps take place. This buffering capability of the UART allows considerable freedom in programming of the communications processor.

A complete program sequence as shown in Figure 4-23 is described below. First, TR is set to 1 and F is set to 5, and the program starts at 5. The program is thus set to start a transmit cycle while it is transferring data from the MPCC memory to the communications section of memory (from MPCC RAM to COMM RAM). The transmit routine is entered only when a flag representing Transmitter Holding Register Empty (THRE) is set, and the receive routine is entered only when the Data Available (DA) flag is set. Tests for these flags are made inside all the data manipulating routines, so the initial program start must enter one of the data manipulating routines (F=5 through 12).

Starting at 5, the program sets starting addresses for data transfers, then sets F=6 so that subsequent returns will step through memory until the routine has moved all data required from MPCC RAM to COMM RAM. The second step in this routine transfers one byte of data from one location in memory to another. A test is then made to see if the routine is complete. If it is, F is set to 7, which is a command to now start formatting data for transmission. If the routine is not complete, a test is made to see if a transmit mode or a receive mode is in progress, i.e., if TR is 1 or 2 (TR <3). Since TR=1, the THRE flag is tested; if true, program sequences to TR, which is now 1. The flow then enters the transmit routine at

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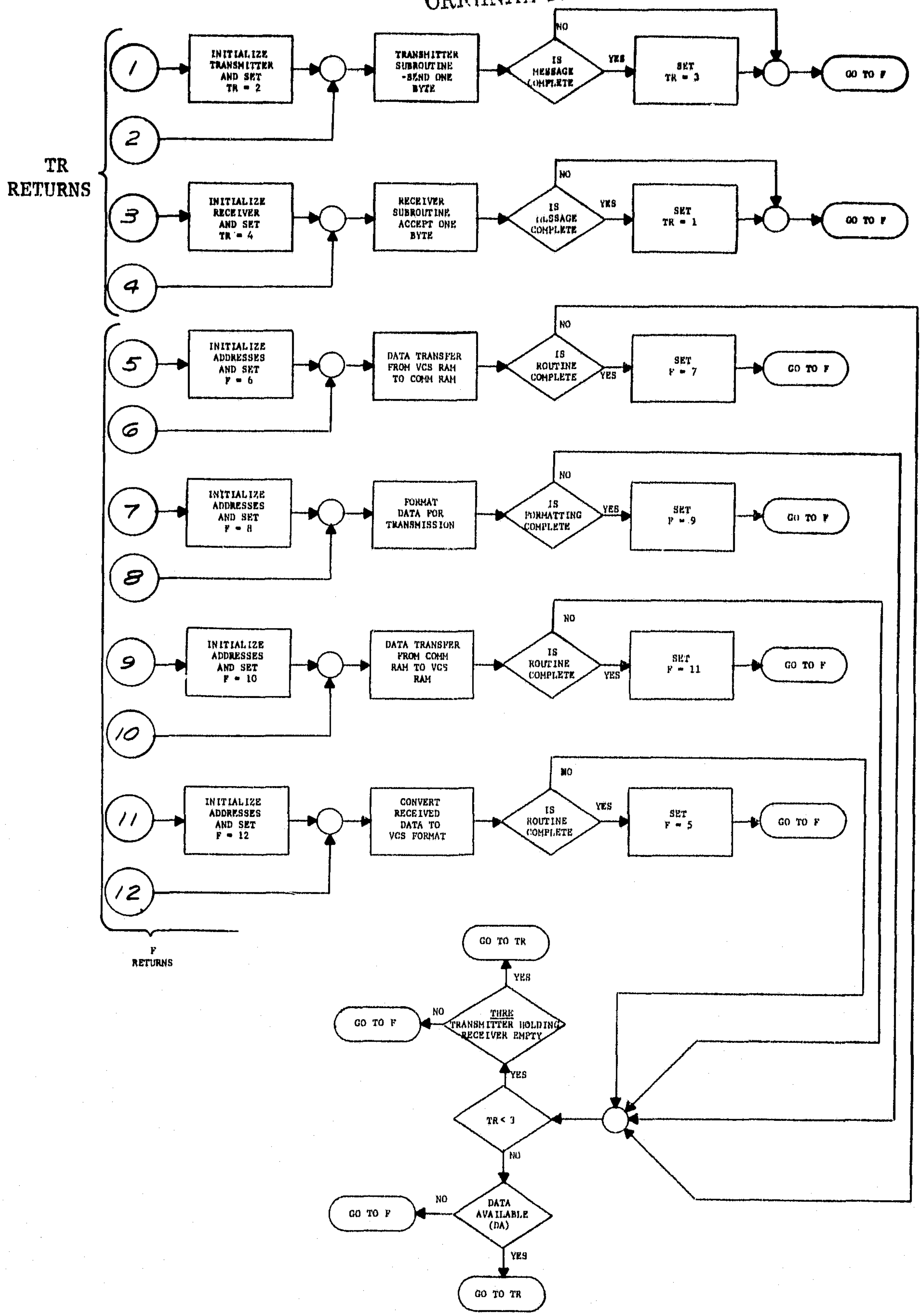

Figure 4-23. ECM Communications Flow Diagram

1, initializes the routine by setting a memory address pointer at the first byte to send and sets TR=2 for subsequent bytes. The routine then sends one byte to the UART and resets THRE. Next a test is made to see if the message is complete, i.e., is this the last word of the message. If true, TR is set to 3, which is the code to start receiving. If not true, TR remains at 2 and control returns to F. At this point, F is still 6, so control returns to the first data transfer routine, which moves another byte from MPCC RAM to COMM RAM. The transmit or receive flag is checked, and if no flag is present, control cycles back through F (now 6) and moves another byte from MPCC RAM to COMM RAM. Since about 90 microprocessor program steps can be completed before the transmitter is ready for another byte, and about 7 program steps are required to complete one data transfer loop about 12-13 bytes can be transfered in memory while one byte is being transmitted or received.

When this data transfer routine is complete, F is set to 7 to start the next routine, which formats data to the form desired for transmission. The first entry to this routine sets starting addresses for data to be read, formated and stored, then sets F=8. One byte of data is formatted and stored for later transmission, then a test is made to see if the routine is complete ($KF \leq KM$). If not completed, the transmit or receive ready flag is tested. If no flag is set, the routine forms another byte and stores it for transmission. This routine continues until the complete message to be transmitted has been prepared, while continuously checking for transmitter or receiver flags. When the formatting routine is complete, F is set to 9 to start the next data handling routine.

The routine to transfer data from COMM RAM to VCS RAM, and the last routine which converts incoming data to forms usable by the control microprocessor operate just like the other two data handling routines. They each loop through program steps until completed, and check for transmit/receive flags on every loop.

Figures 4-24 through 4-27 shows more detailed flows for the six routines mentioned above plus one special routine which is used to update ECM calibration. The entry to the special routine is caused by special code words from the MCS, which are handled in the receiver routine. The receiver routine is discussed below in some detail followed by the lead in to the special routine that updates the VCS.

Figure 4-24 shows the flow diagram for the receiving data routine, with initial entry at 3 and subsequent entries at 4. On the first entry, a byte is read from the UART into the communications processor D-register. There are 3 error checks made on incoming data: parity error, overrun error, and framing error. These error flags are sampled by an OR gate, and if true, the byte is ignored and control exits to another function. If no read error occurs, the D-register

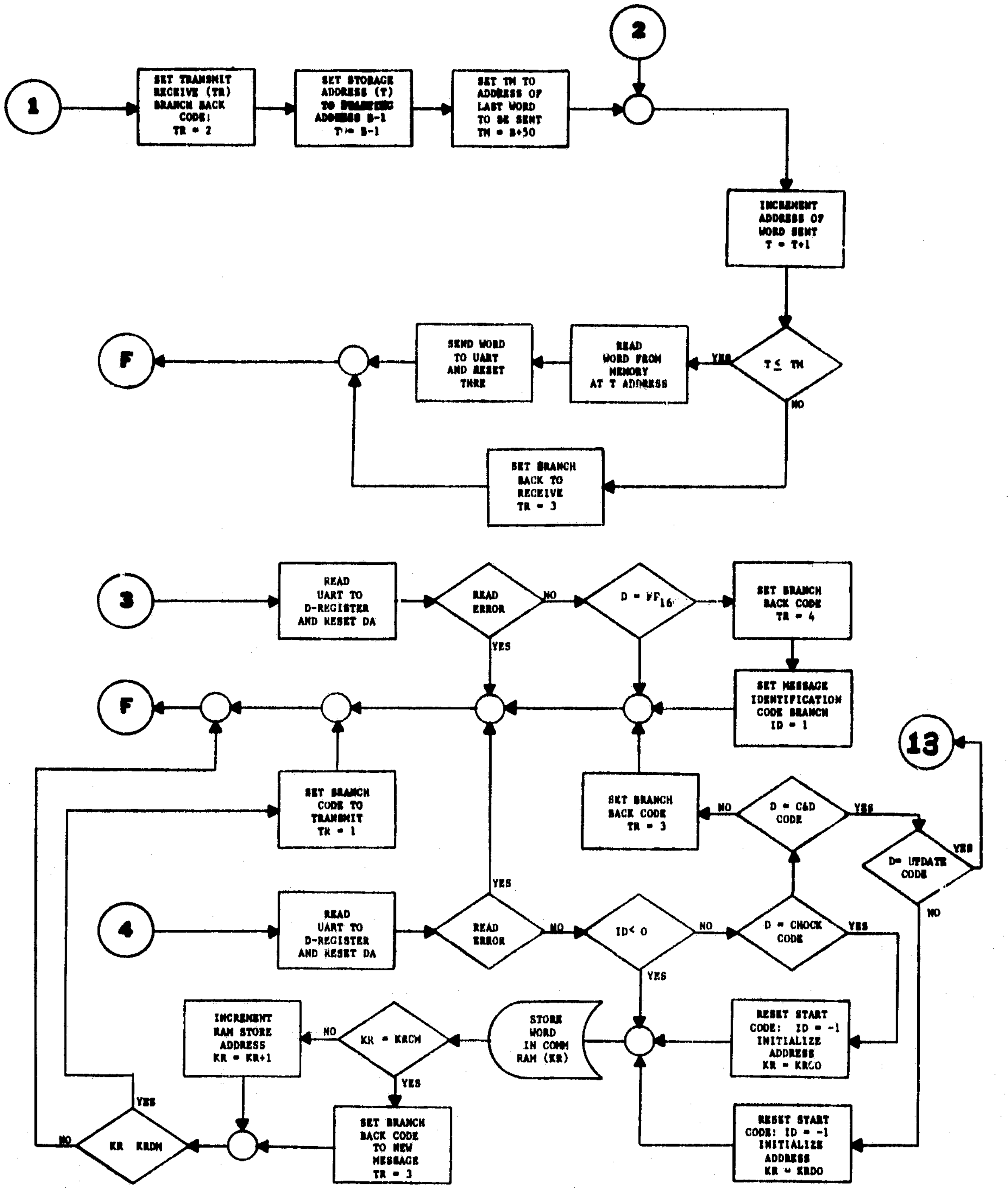

Figure 4-24. ECM Transmit and Receive Flow Diagram

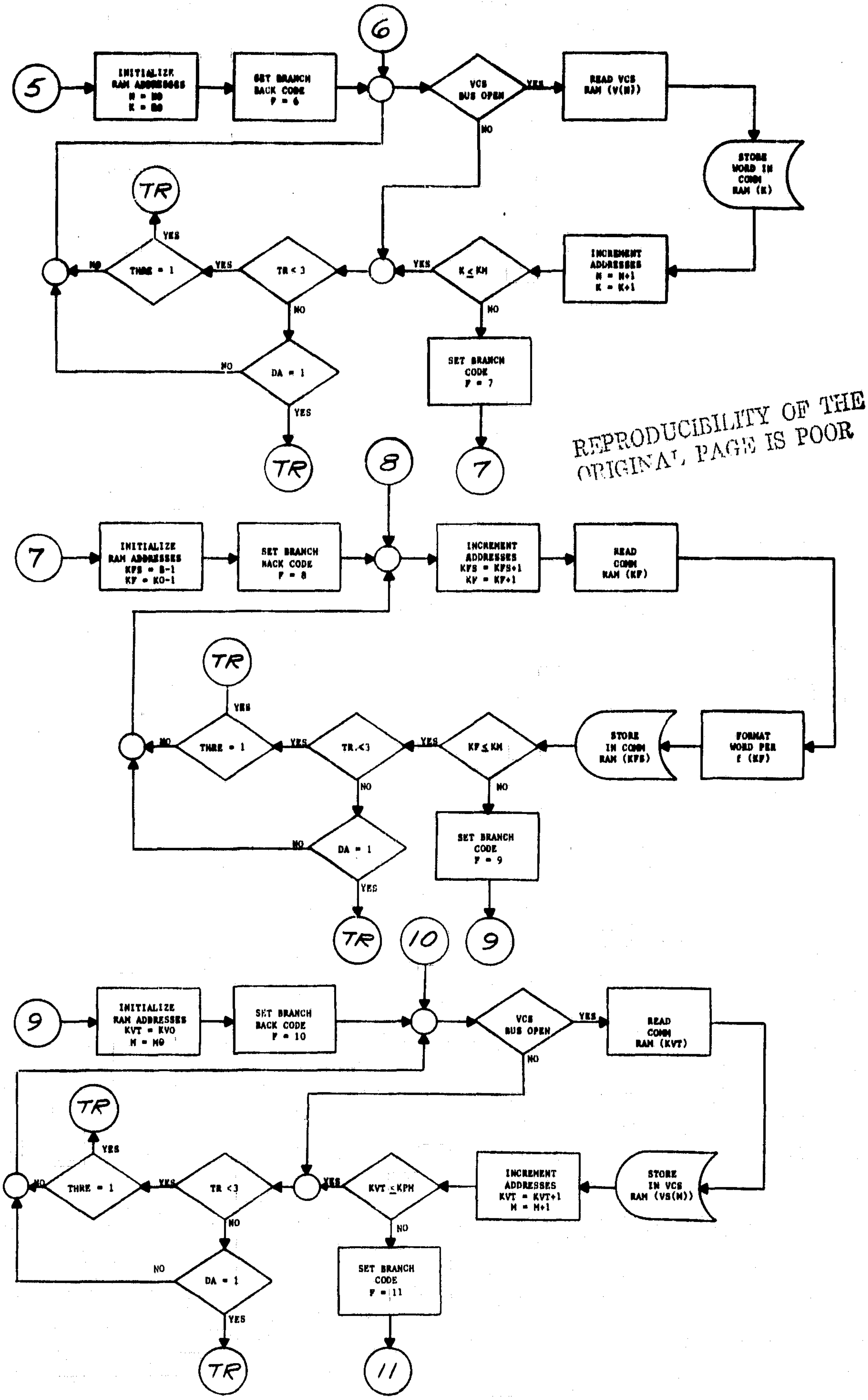

Figure 4-25. Data Handling Flow Diagrams

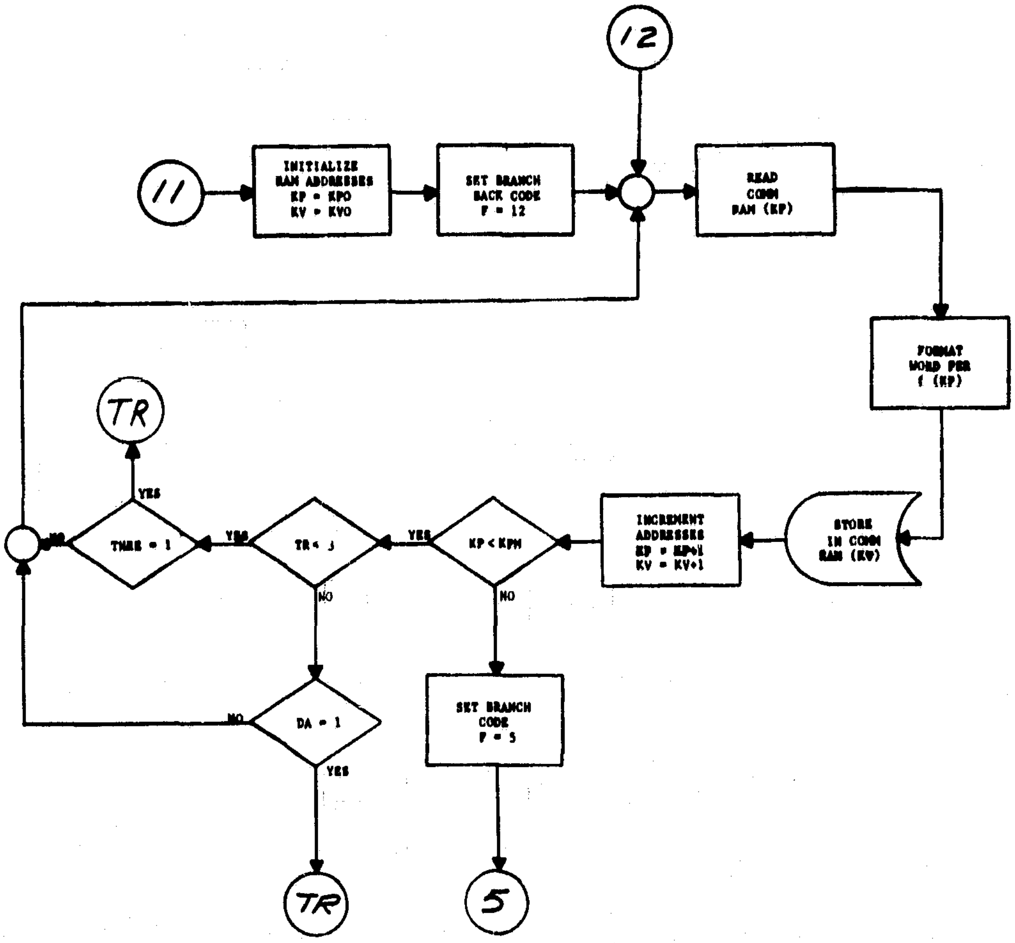

Figure 4-26. Data Formatting Flow Diagram

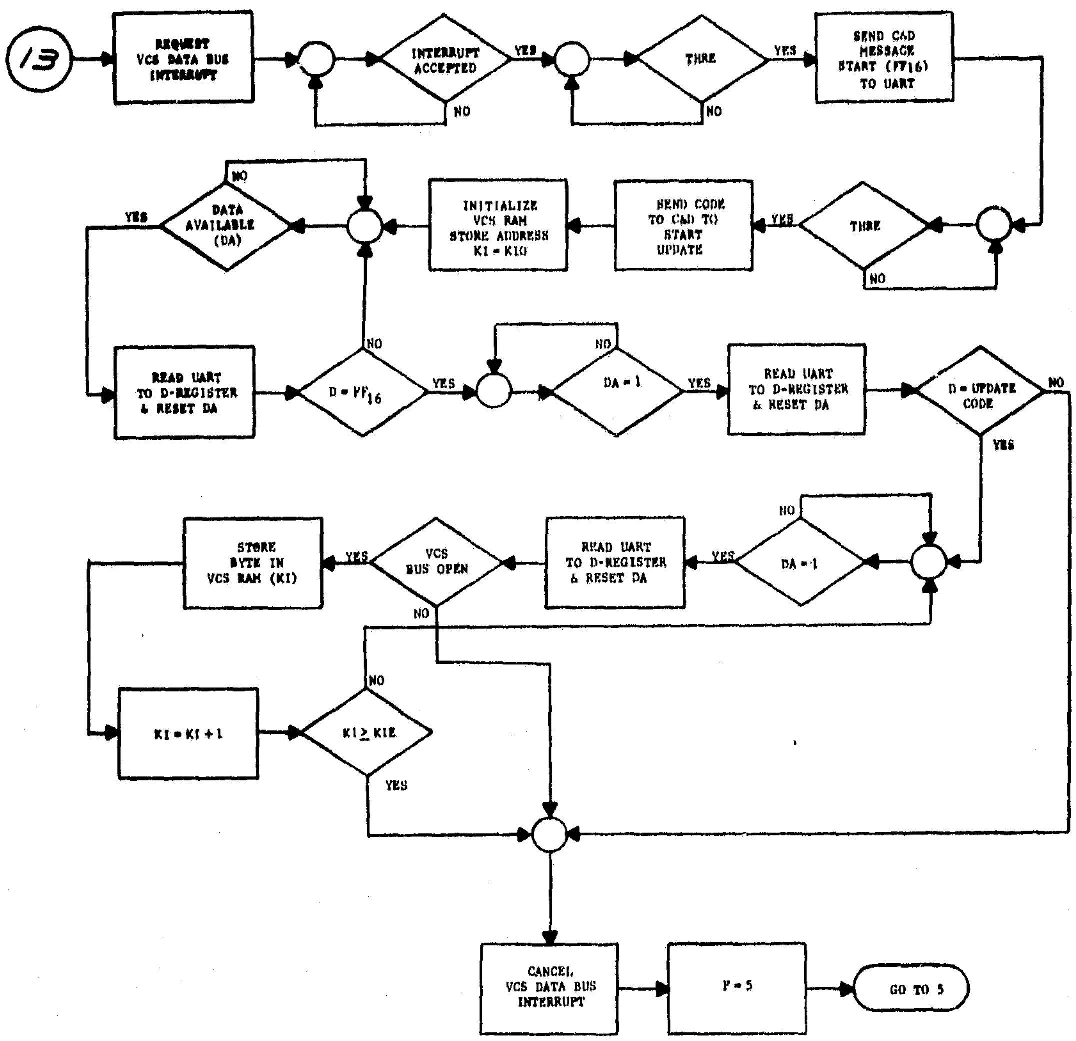

Figure 4-27. ECM Parameter Update Communications Flow Diagram

contents are compared to the start message code, which is FF_{16} (11111111). The program is exited immediately until a start code is obtained. When a start message occurs, TR is set to 4, and an identification required message is set by setting ID=1. This code indicates that the next word received must be an identification code.

When entry occurs at 4, data is read from the UART to the D-Register. Again, if a read error occurs, program control exits, if not, ID is checked to see if an identification code is expected. If a code is expected, it is tested to see if it is a Roof Support or a MCS code. If it is a Roof Support code, the initial address for storing data is set for roof support data and ID is set to -1. If it is a MCS code, it is also checked to see if it is a special update message code. If it is not an update, but a normal MCS message, the initial address for storing data is set for MCS data, and ID is set to -1. Once identification of the message is established, subsequent words received are stored sequentially until the given message is completed. When a normal C&D message is completed, TR is set to 1 for transmission mode.

When the receiver routine examines the identification word and finds that it is a special update signal from the MCS, the routine exits to 13, which is discussed in the following section.

4.4.7 VCS Communications Update - There are a number of parameters within functions performed in the ECM MPCC which require updates as mining conditions or sensor characteristics change. To allow for a data load that will define these parameters whenever desired from the Digital Address System (DAS) on the MCS C&D panel, a separate receive routine was generated as shown in Figure 4-27.

To allow the communications processor MPCC to operate in parallel without interference on the data bus, a bus isolator is placed between the two systems. The isolator is under exclusive control of the MPCC and cross communications can only occur when the isolator is open. During normal data shuffling between memories that is done by the communications processor, the bus isolator is opened periodically by the control processor and a signal is sent to the communications processor to use the bus as needed. This procedure is shown in all the data handling routines as a test on "VCS BUS OPEN."

In this special routine, it is necessary to cause the isolator bus to be opened and remain open until the complete update message is received. This is done under the assumption that all control functions are suspended anyway until the update is accomplished.

The update routine is entered at 13 when an update code has been received from the MCS. The communications processor immediately sends an interrupt request to the control processor, requesting that the MPCC bus be opened. The control processor must respond by suspending all control functions in an orderly fashion, then opening the data bus and remaining in a pause mode until the interrupt request is cancelled by the communications processor at update completion.

The communications processor then tests to see if the interrupt request has been acknowledged. The communications processor then sends a message start code (FF_{16}), followed by a start update code to the C&D panel. The communications processor then initializes the storage address locations in control processor RAM where the update data is to be stored. The communications processor then reads the UART for input bytes from the MCS. The first byte must again be a start message, the second byte must be an update code, then subsequent bytes are received and stored directly in MPCC RAM locations until the update is complete. When the update is complete, the MPCC interrupt request is cancelled, and normal routines are re-established by setting F=5 and returning to entry point 5.

During the update procedure, the communications processor does not perform any other functions, which means it is idle for considerable portions of time as it is in a pause mode while waiting for bytes to be shifted into the UART register. The control processor simply waits for a cancellation of the interrupt request for the complete update time.

4.4.8 Voice Communications - An audio channel will be carried on the communications line in digital form, with high and low bits formed by frequency shift keying like the data channel but at a different carrier frequency. This will be done with a voice transmitter channel consisting of microphone, audio amplifier, an A/D converter, a frequency shift keyed modulator, and a summing amplifier or mixer to add the signal to the data signal before the line driver amplifier. The receiver channel consists of an active filter tuned to pass the two digitized voice frequencies, a frequency shift keyed demodulator, a D/A converter, an audio amplifier, and a speaker. Each subsystem within the longwall system where voice communications is desired will have similar input/output channels.

The A/D converter that will be used in the voice channel is a CMOS He55516 or equivalent, Continuously Variable Slope Delta Modulator (CVSD), which converts voice signals to serial digital data. Switching a logic level on a selector imput allows the same unit to re-convert digital data into voice. This CVSD unit is optimized for 16 K bits/sec, and is usable down to 9 K bits/sec. Fidelity may be increased by using a higher frequency unit, the HC55532, which is optimized for

32 K bits/sec, and is usable beyond 64 K bits/sec. The particular bit rate chosen will be set by a separate clock frequency on the data line. The communications clock will be located at the master control station.

This digitizing of voice technique was chosen to transmit the voice over the digital data line in order to take advantage of new technology developed for enhancing performance for a lower cost. This technique will provide a relatively noise free voice link through the line driver and cable used for the data link. Other techniques, such as FM are also available and could be transmitted through the data cable, however, for this preliminary design the digital technique was chosen.